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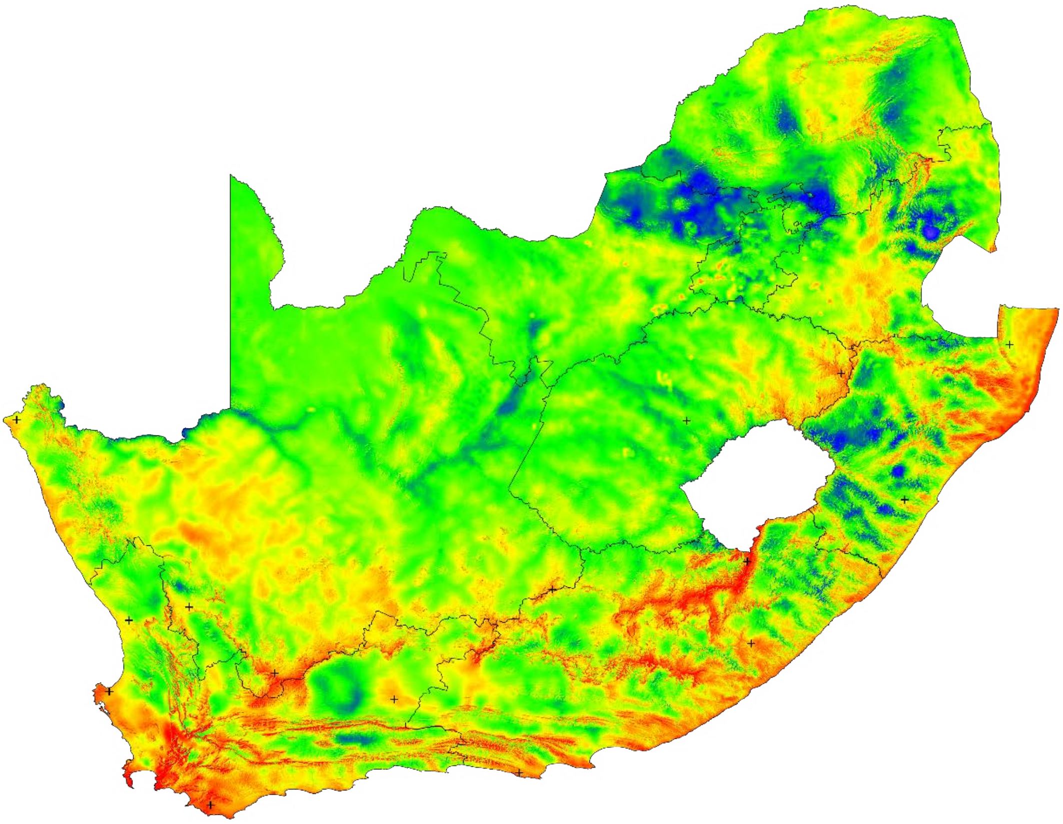

Interim High-Resolution Wind Resource Map for South Africa 2017

Niels G Mortensen, Andrea N Hahmann, Jens Carsten Hansen, Duncan N Heathfield

DTU Wind Energy E-0178

November 2017

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Contents

1. Introduction

The objective of this work has been "*To develop a Fast-Track WASA Wind Atlas and Wind Resource map with databases in time to assist with CSIR DEA SEA Phase 2 and WASA 2, and that cover all of South Africa*", according to the Terms of Reference.

This has been taken to mean that the results are generated as follows:

1. Maps are research-based, taking into account the latest knowledge; if at all possible
2. Maps and data had to be done in a short period of time; about two months only
3. Maps are based on the full wind atlas methodology used in WASA 1 and 2
4. Maps are high resolution, 250 m, and given for three heights, 50, 100 and 200 m
5. Maps cover all of South African land mass, and are divided into provinces
6. Databases of main SEA 1 results for all of South Africa are GIS compatible
7. Databases of additional SEA 2 results are comprehensive, i.e. contain Weibull *A*- and *k*-parameters and frequencies of occurrence for 12 sectors and three heights at all nodes.
8. Database of 3-km wind atlas files cover the original WASA1 domain
9. Database of 5-km wind atlas files cover practically all of South Africa

The work reported here, and the results obtained, are necessarily of an interim nature. This is a feature and hallmark of the WASA project and approach; that the methods used are developed constantly and that the result therefore may improve over time as updated models, procedures and data become available. Improved maps and data will therefore be presented in the WASA Phase 2 and WASA Phase 3.

The timing of the present work has been crucial, so it was assumed that the topographical inputs to the microscale flow modelling would be the same as for the 2014-mapping of the WASA 1 domain. The improvements to the present maps are thus mainly related to the national coverage, the mesoscale modelling results, the downscaling of these to generalised wind climates, and the microscale modelling.

Nevertheless, the topographical inputs to the WAsP microscale modelling were redone for all of South Africa – from downloading the raw data to producing the elevation and roughness length grids for each province – in order to provide for recent, coherent, and high-quality data sets.

In WASA Phase 1 and 2, several elevation data sets were analysed and compared in order to find the data set that would produce the most reliable results for the least amount of effort and resources – as well as a data set that could be recommended to the wind energy community in South Africa. This work will continue in Phase 2 and 3, in which several land cover data bases are being analysed and compared in similar way. Likewise, the variation of atmospheric stability over South Africa will be investigated, in order to obtain the best possible detailed wind resource maps at the end of WASA Phase 3. It is therefore anticipated that future versions of the wind atlas data sets and detailed wind resource maps will improve e.g. because of the improved land cover and stability information.

The *Fast-Track WASA Wind Atlas and Wind Resource map with databases* are validated by comparing modelled results to the observed wind climates at the 10 WASA1 masts and the 5 WASA2 masts. The present report is the 'Final report' for WP34.01x WASA 3 DEA SEA Fast Track (DTU).

2. Interim High-Resolution Wind Resource Maps

The deliverables associated with the high-resolution wind resource mapping are described below.

2.1 Wind resource maps

The deliverables consist of validated numerical wind atlases and detailed wind resource maps for WASA 1 domain, WASA 2 domain and the rest of South Africa.

The numerical wind atlases – or generalised wind climate data sets – have been generated by the Weather Research and Forecasting (WRF) model and the DTU downscaling procedure. In this section we show only one representation of these numerical wind atlases, i.e. the mean generalised wind speeds at 100 metres above ground level over a flat uniform roughness length of 3 cm. The data sets are described further in the remainder of the report.

Detailed wind resource maps and data have been generated with the WAsP Resource Mapping system (aka Frogfoot), see below. For each modelling domain and province, results are given in grid format with a cell size of 250×250 metres and for three heights of 50, 100 and 200 m above ground level (a.g.l.). The detailed wind resource maps depict:

- Mean wind speed U in [ms^{-1}]
- Mean power density P in [Wm^{-2}]
- Elevation z above sea level in [m]
- Ruggedness index RIX

2.1.1 WASA Phase 1 domain

The WASA Phase 1 domain maps are based on a new 3-km validated numerical wind atlas, see Figure 1. This map represents the wind potential from which the detailed wind resource maps in Figure 2 and Figure 3 were derived, see Appendix B.

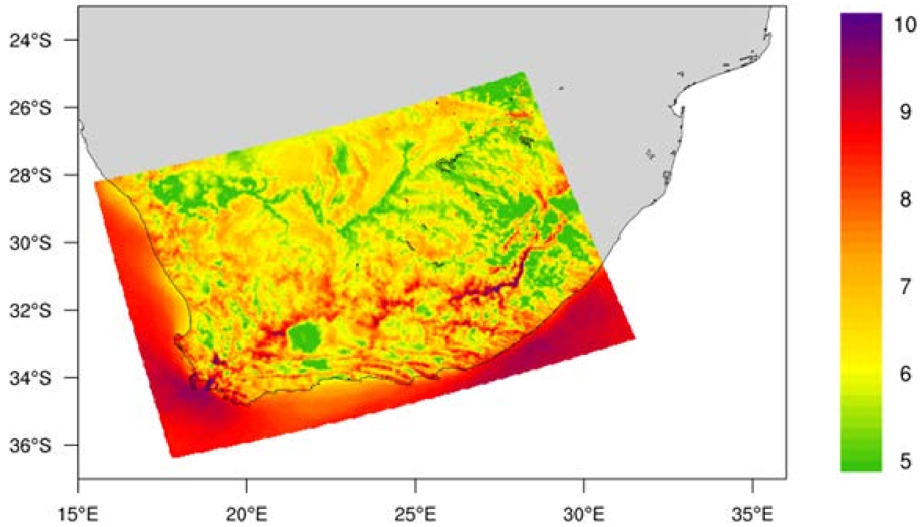

Figure 1. Numerical wind atlas map: Mean generalised wind speed [ms^{-1}] at 100 m above ground level over a flat and homogeneous surface of constant roughness (z_0 = 3 cm) for the period 1 October 2005 to 30 September 2013 for the WASA 1 domain (3 km×3 km).

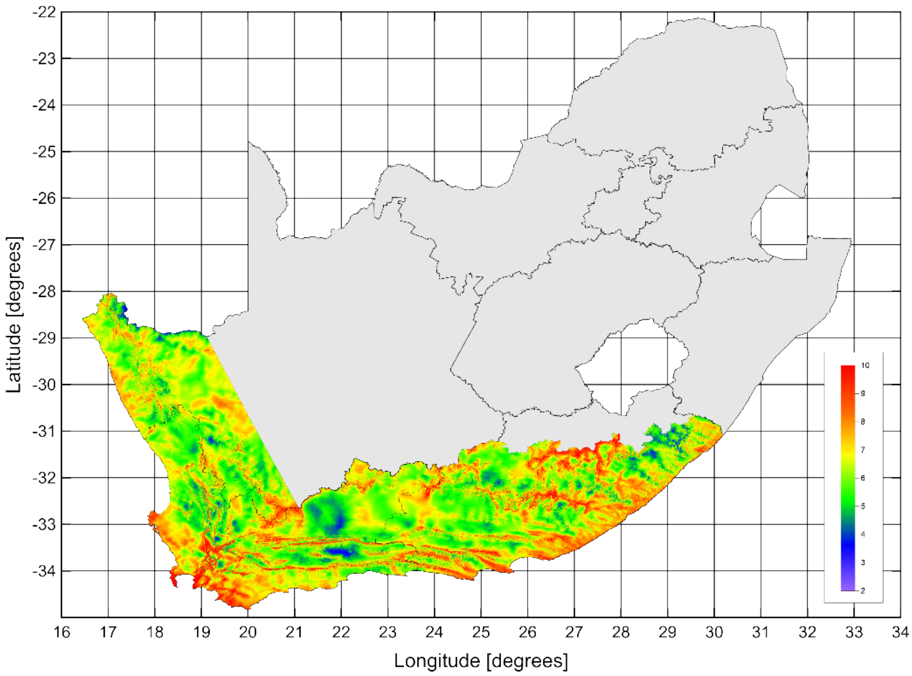

Figure 2. Detailed wind resource map: Mean wind speed at 100 m above ground level for the WASA 1 domain.

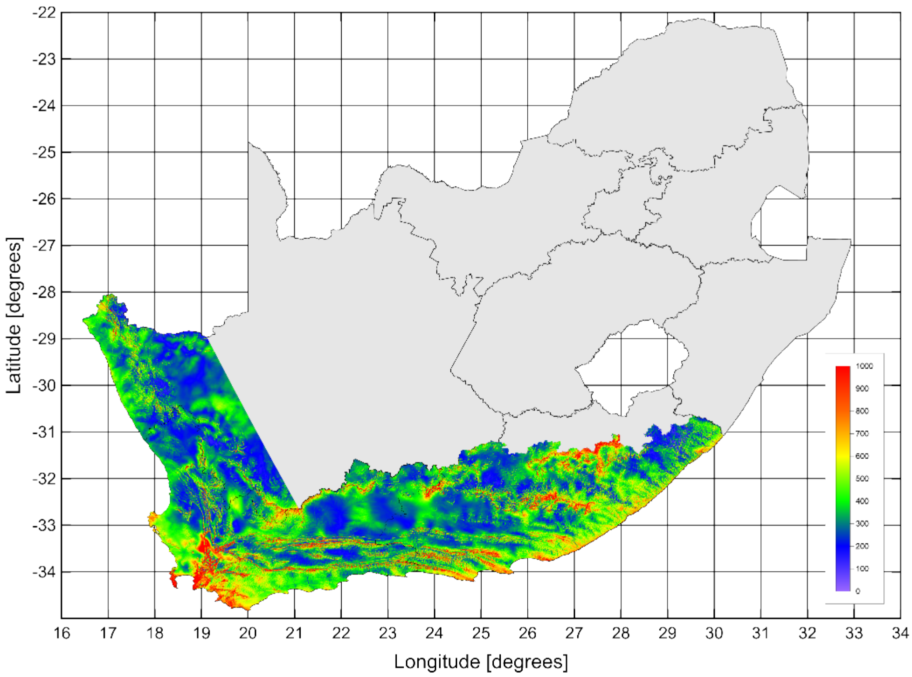

Figure 3. Detailed wind resource map: Mean power density at 100 m above ground level for the WASA 1 domain.

2.1.2 WASA Phase 2 domain

The WASA Phase 2 domain maps are based on a new 5-km validated numerical wind atlas. However, since this atlas covers most of South Africa, wind resource maps were calculated for most of South Africa, see below.

2.1.3 Rest of South Africa

The rest of South Africa is based on a new 5-km numerical wind atlas as described above (Figure 4), except for an area of Limpopo north of 24 degrees south where such data were not available. Here, the wind resource maps are based on a 15-km numerical wind atlas, (Figure 5). In the detailed maps shown below, Figure 6 and Figure 7, the 5- and 15-km data are shown in the same map. In addition to the wind resource maps, maps and data showing model elevation and terrain ruggedness index have also been produced, see Appendix C.

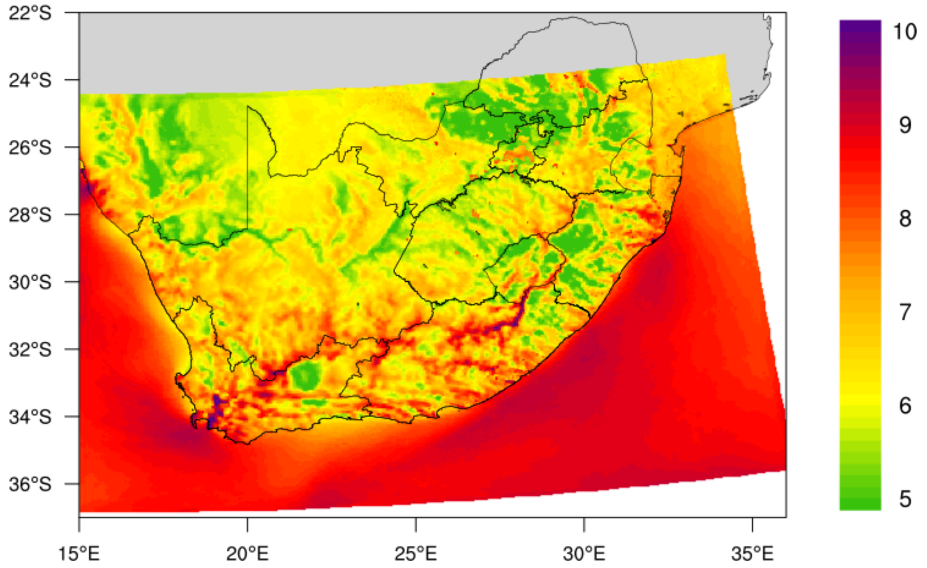

Figure 4. Numerical wind atlas map: Mean generalised wind speed [ms^{-1}] at 100 m above ground level over a flat and homogeneous surface of constant roughness (z_0 = 3 cm) for the period 1 October 2005 to 30 September 2013 for the WASA 2 domain (5 km×5 km).

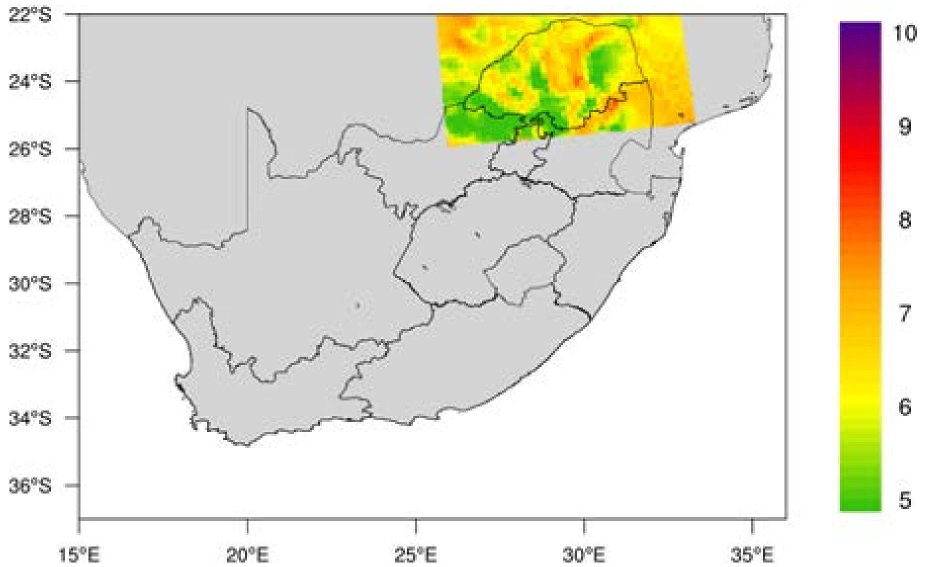

Figure 5. Numerical wind atlas map: Mean generalised wind speed [ms^{-1}] at 100 m above ground level over a flat and homogeneous surface of constant roughness (z_0 = 3 cm) for the period 1 October 2005 to 30 September 2013 for the WASA 2 domain (15 km×15 km).

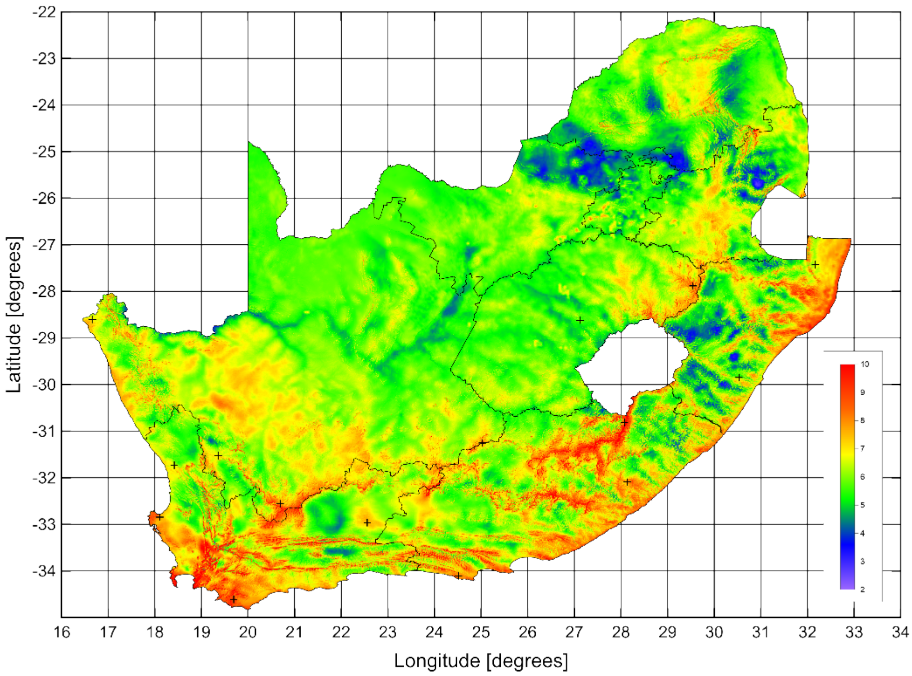

Figure 6. Detailed wind resource map: Mean wind speed at 100 m above ground level for South Africa.

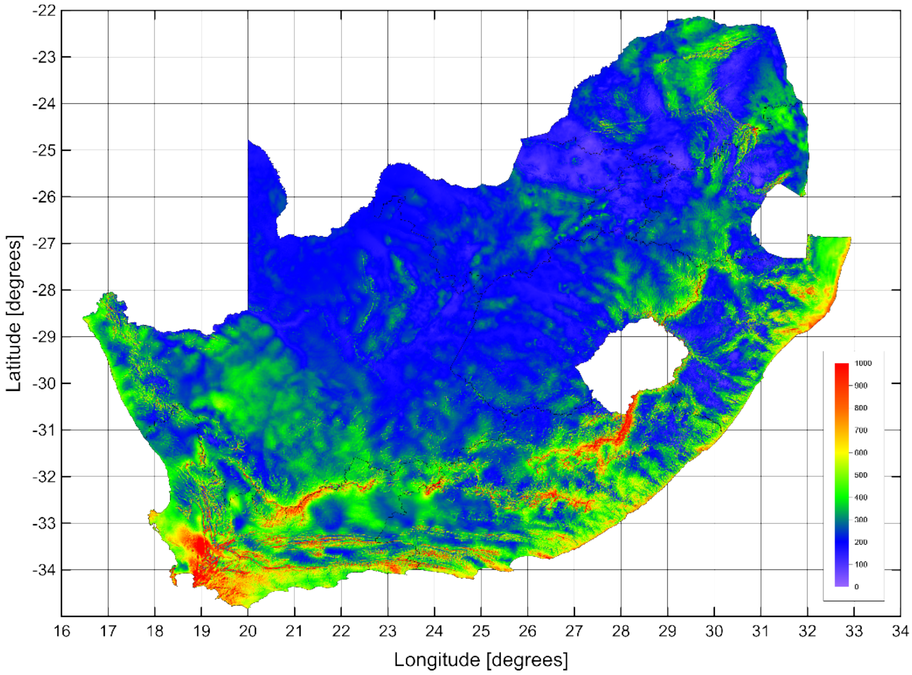

Figure 7. Detailed wind resource map: Mean power density at 100 m above ground level for South Africa.

2.2 Data formats and metadata

Data and metadata for *wind resource maps* are delivered similarly to CSIR DEA SEA Phase 1:

- ArcGIS ASC files. Four ASCII files per province; distributed in ZIP archives.
    - Three ZIP archives for WASA 1 domain (EC, NC, WC) @ 3 km
    - Nine ZIP archives for the nine provinces of ZA @ 5 km
    - One ZIP archive for Limpopo north of 24 deg. S @15 km

- Adobe PDF documents, see Appendix B.
  - One metadata document for WASA 1 domain @ 3 km
  - One metadata document for WASA 2 and rest of ZA @ 5 km (15 km)

Data and metadata for *numerical wind atlases* are delivered similarly to DEA SEA Phase 1:

- ASCII LIB files. One WAsP LIB file for every mesoscale modelling node
  - 37,847 LIB files for WASA 1 domain @ 3 km
  - 44,326 LIB files for WASA 2 domain @ 5 km
- ASCII CSV files. One file with node positions per mesoscale data set
  - One CSV file for WASA 1 domain @ 3 km
  - One CSV file for WASA 2 domain @ 5 km
- ASCII DAT files. One file with node positions per mesoscale data set
  - One DAT file for WASA 1 domain @ 3 km
  - One DAT file for WASA 2 domain @ 5 km

Data for *database of wind climatologies* are delivered as

- ASCII TXT files. One ASCII file per province; distributed in ZIP archives.

2.3 Database of SEA 1 characteristics

The database of SEA 1 characteristics contain four grids of predicted wind climates and topographical characteristics for each province:

- Mean wind speed *U*: 10 min average in [ms^{-1}]
- Mean power density *P*: 10 min average in [Wm^{-2}] (w/ site-specific air density)
- Elevation z: meters above sea level in [m]
- Ruggedness index RIX: using WAsP standard parameters

The database of SEA 1 characteristics can be downloaded from the WASA download site, see Appendix D.

The databases of generalised wind climates (wind atlas files) in WAsP LIB format (Mortensen et al., 2014d) can also be downloaded from the WASA download site, see Appendix D.

2.4 Database of SEA 2 characteristics

For each province, the following information is provided in ASCII TXT format files:

- Weibull A- and k-parameters for 12 sectors at each 250-m node and height
- Wind direction distribution (rose) for 12 sectors at each node and height

Wind climate and energy information is given for 50, 100 and 200 m above ground level. Climate information at each of the 250-m modelling grid points will make it possible to calculate, say, specific mean power density from 0-25 ms^{-1}, energy yield for any given wind turbine, capacity factor for any given wind turbine, etc.

Data are stored in ASCII text files with the following format:

- JobID; x; y; z; SectorIndex; A; k; f;

where x is UTM Easting [m], y is UTM Northing [m], z is height above ground level [m], SectorIndex is a sector index from 1 to 12 clockwise starting from north, *A* is Weibull scale parameter [ms^{-1}], *k* is the Weibull scale parameter, and *f* is sector frequency. The TXT files are distributed in ZIP archives. The database of SEA 2 characteristics can be downloaded from the WASA download site, see Appendix D.

3. Methodology

The same methodology that was used in the development of the WASA1 Wind Atlas and Wind Resource map and input into DEA SEA Phase 1 has been used for the development of the Interim High-Resolution Wind Resource Map for South Africa, see Figure 8. This has been possible because the *DTU Generalization* procedure and *WAsP Resource Mapping System* (aka Frogfoot) have been available and could produce the required results within the given time frame (Sep 2017 to Oct 2017) for input into the DEA SEA Phase 2.

The DTU Generalisation procedure is required to link the mesoscale and microscale modelling, in order to downscale the large-scale wind climate to specific sites in South Africa. Importantly, the generalisation procedure works with the industry-standard WRF (Weather Research and Forecasting) model.

The Frogfoot modelling system is required to automate the microscale modelling (WAsP 11 application) for large areas at high speed. Frogfoot uses the microscale models in a batch-like operation mode, through distributed computing in a network. It features automatic selection of regional wind climates (LIB files) and interpolation of regional wind climates to specific sites; in order to provide a continuous wind resource map. Importantly, the Frogfoot system works with the industry-standard WAsP software engine and models.

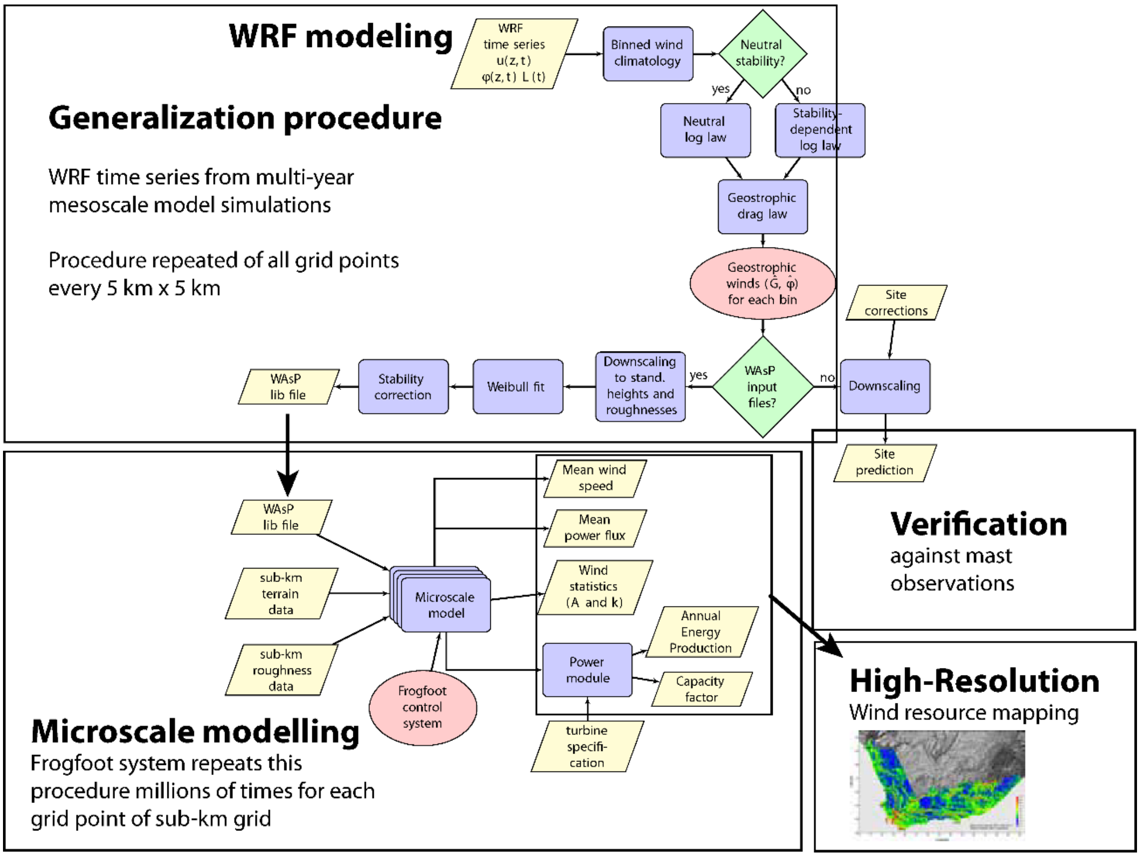

Figure 8. Schematic diagram showing the relationship and flow of data between the components of the Frogfoot system. Blue boxes represent core components of Frogfoot, red boxes represent ancillary components, purple boxes represent data that is input into the system, and the green box represents the result outputs.

3.1 Mesoscale modelling – WRF and DTU generalization

The wind climatologies that form the base of the interim wind atlas were created using the Weather, Research and Forecasting (WRF; Skamarock et al. 2008). The WRF model is a mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. The WRF modelling system is in the public domain and is freely available for community use. It is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. The WRF model is used worldwide for a variety of applications, from real-time weather forecasting, regional climate modelling, to simulating small-scale thunderstorms.

Although designed primarily for weather forecasting applications, ease of use and quality has brought the WRF model to be the model of choice for downscaling in wind energy applications, including the WASA1 wind atlas released in 2014 (Hahmann et al., 2015a).

A first mesoscale simulation for the Interim High-Resolution Wind Resource Maps was carried out with WRF version 3.8.1 released 12 August 2016. After comparison with the results of the WASA1 simulation, it became clear that this simulation had a general overestimation (up to 4 m/s in some areas) of boundary layer winds over land. This was due to changes in the PBL scheme, which were not properly described in the model release. Therefore, a decision was made and the simulation was rerun using WRF version 3.6.1 model released on 14 August 2014, and the results presented here use the output from this simulation.

For the Interim High-Resolution Wind Resource Maps, the WRF model was setup using the parameters described in Table 1 and follows the method described in Hahmann et al. (2015b). The simulations were integrated on a grid with horizontal spacing of 45 km×45 km (outer domain, d01, with 122×110 grid points), 15 km×15 km (first nested domain, d02, with 247×211 grid points) and 5 km×5 km (second nest, d03, with 271×379 grid points). A map of the model setup location, which was slightly rotated to better cover the region of interest over southern Africa, is displayed in Figure 9.

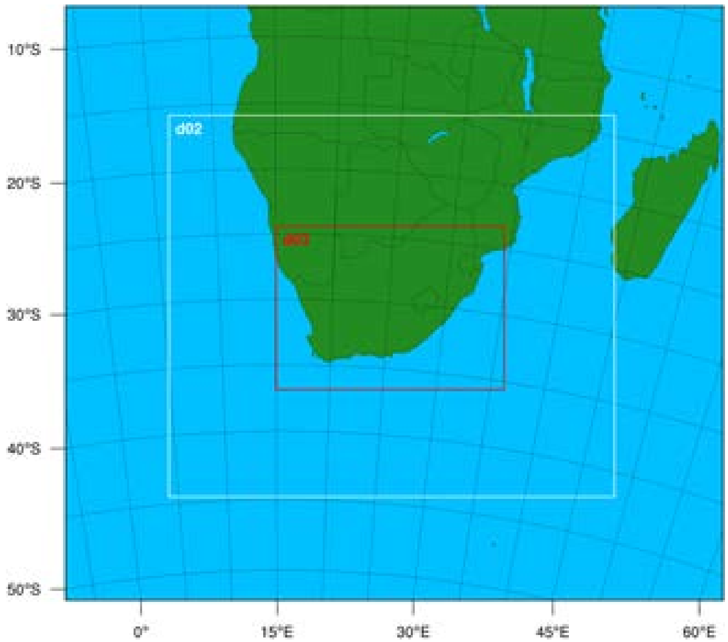

Figure 9. WRF domain configuration used to generate the mesoscale wind climatologies used in the Interim High-Resolution Wind Resource Map.

The elevation of the terrain, land cover category and surface roughness length used in the inner domain of WRF (d03, Δx=5 km) is shown in Figure 10.

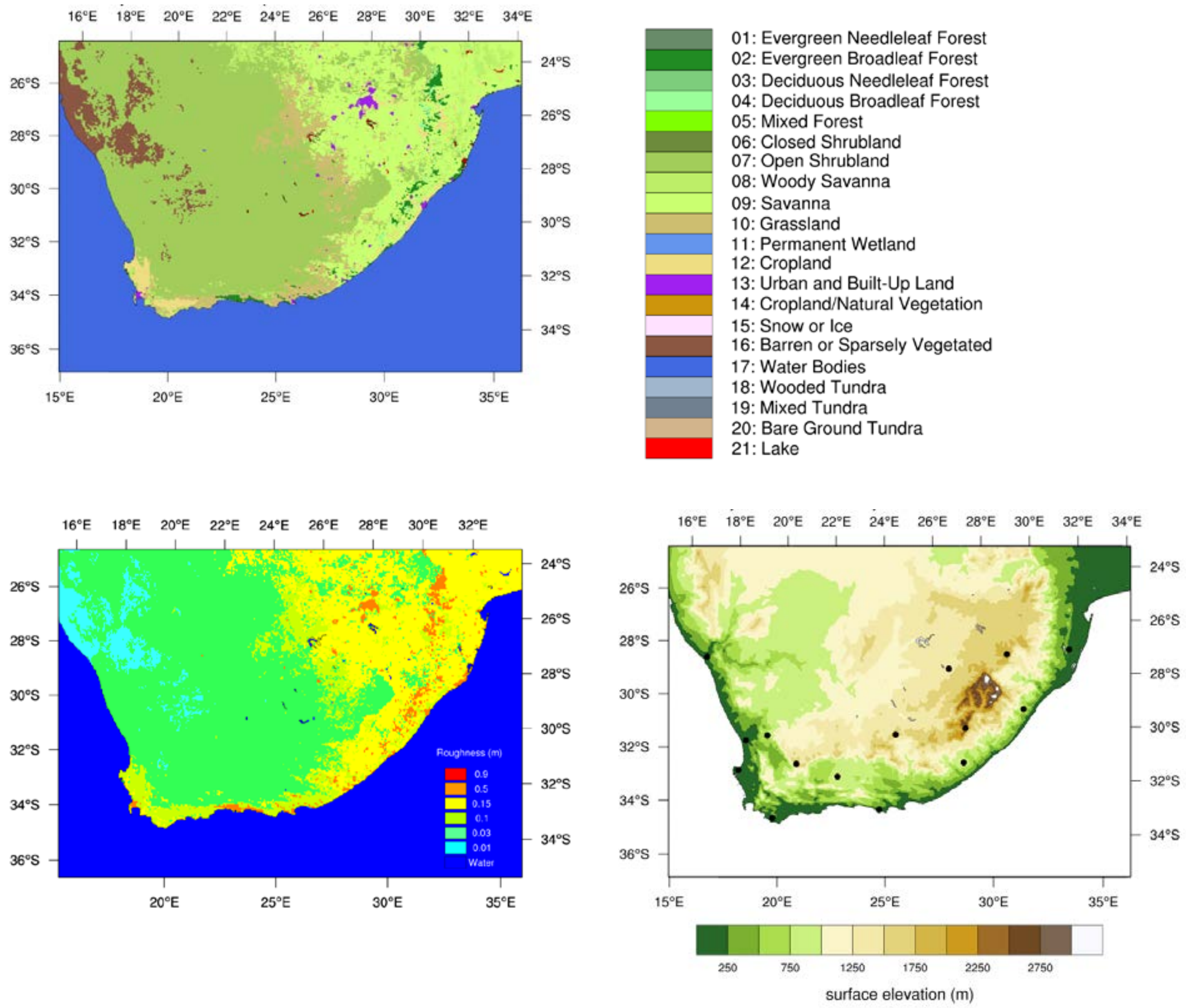

Figure 10. The d03 WRF land surface in land cover (top left), surface roughness length (m; bottom left) and surface elevation (m; bottom right).

Table 1. Model setup parameters used in the WRF model simulations.

Model setup
• WRF (ARW) Version 3.6.1. • Lambert conformal projection. Reference latitude and longitude 30.0°S, 25.5°E, standard longitude 15.5°E. • Horizontal grid spacing: 45 km (d01), 15 km (d02) and 5 km (d03); • Grid size: 122×110 (d01), 247×211 (d02) and 271×379 (d03). • 61 vertical levels with model top at 50 hPa; 20 of these levels are placed within 1000 m of the surface; the first 9 levels are located approximately at: 6, 22, 40, 57, 73, 91,113, 140, 170 m. • MODIS (2001–2010) land cover classification of the International Geosphere-Biosphere Programme. Dominant land cover category. • Period: 2005-10-01 to 2013-09-30, for running the downscaling (but a longer period was run 2005-09-28 to 2017-06-26). • Surface roughness lengths are modified as in Hahmann et al. (2015a).
Simulation setup
• Initial, boundary conditions, and fields for grid nudging come from the European Centre for Medium Range Forecast (ECMWF) ERA-Interim Reanalysis (Dee et al., 2011) at 0.75°×0.75° grid spacing. • Runs are started (cold start) at 00:00 UTC every 10 days and are integrated for 11 days, the first 24 hours of each simulation are disregarded. • Sea surface temperature (SST) and sea-ice fractions come from the dataset produced at USA NOAA/NCEP at 0.25°×0.25° grid spacing (Reynolds et al, 2002) and are updated daily. Period: • The full simulation covers the period 28 September 2005 - 26 June 2017, but only the period 1 October 2005 - 30 September 2013 is used to generate the lib files used to drive the WAsP Frogfoot calculation. • Model output: output frequency of 20 minutes for d03 (lowest 13 vertical levels, highest: ~340 m), hourly for d01 and d02. Organized in daily files. • Time step in most simulations: approx. 90-360 seconds, using adaptive time step. One-way nested domains; 5 grid point nudging zone. • Grid nudging on d01 only and above level 15; nudging coefficient 0.0003 s^{-1} for wind, temperature and specific humidity. No nudging in the PBL.
Physical parameterizations
• Precipitation: WRF Single-Moment 5-class scheme (option 4), Kain-Fritsch cumulus parameterization (option 1) turned off on D3. • Radiation: RRTMG scheme for longwave (option 4); RRTMG shortwave for shortwave (option 4). • PBL and land surface: Nakanishi and Niino PBL scheme (Nakanishi and Niino (2006) (option 5), MYNN surface layer (option 5) surface-layer scheme, and Noah Land Surface Model (option 2). • Surface roughnesses are kept constant at their winter (lower) value. • Diffusion: Simple diffusion (option 1); 2D deformation (option 4); 6th order positive definite numerical diffusion (option 2); rates of 0.06, 0.08, and 0.1 for d01, d02, and d03, respectively; vertical damping. • Positive definite advection of moisture and scalars.

The wind atlas method is based on the generalization of the wind climatologies derived from the mesoscale modelling. The post-processing allows a proper verification to be carried out, in which wind climate estimates derived from mesoscale modelling and measurements can be compared. Without the post-processing step no verification is possible, because the surface description within the model does not agree with reality, and therefore model winds will not agree with measured winds, except perhaps in extremely simple terrain or over water far from coasts.

For the Interim High-Resolution Wind Resource Maps the generalization method is that outlined in Hahmann et al (2015) with a few small errors that have been corrected from previous versions of the generalization code. The parameters used are listed in Table 2. The parameters used are listed in Table 2. However, a few small errors have been corrected from previous versions of the generalization code. Therefore, new WAsP wind climate files ("lib" files) have been created both for the WASA1 (Hahmann et al 2015) and this new fast-track simulation. In the verification in Section 3.3, we evaluate the WRF-derived lib files for both the old and the new simulations.

Table 2. Parameters used in the generalization procedure.

Generalisation parameters	
Method: 3 (stability dependent)	ain_neut = True
levfreq = 100 m	nsec = 36
decayl = 1.5×10^4	Ocean roughness from WRF simulation

3.2 Microscale modelling – WAsP Resource Mapping System

The calculation system used for the Interim High-Resolution Wind Resource Maps is called the *WAsP Resource Mapping System* (aka Frogfoot). It has been developed in association with the software development company World In A Box. The motivation for the development of Frogfoot was to allow high-resolution WAsP-like calculations of predicted wind climates to be made over large areas, using a large number of generalized wind climates. This need came about because of numerical wind atlases being carried out on nation-wide scale which generated generalized wind climates on a grid with a spacing of, typically, 5 km.

The Frogfoot system employs the same flow modelling as WAsP (Mortensen *et al.*, 2014d). Unlike the present WAsP 11.6, the terrain descriptions can be input using raster maps, rather than vector maps. Also unlike the present WAsP, the starting point for describing the large-scale wind forcing is any number of geographically distributed generalized wind climate files (LIB files), whereas WAsP 11.6 can only use one at a time. The following edited excerpt from science.globalwindatlas.info (Badger and Mortensen, *personal communication*) describes the Frogfoot system in some detail.

3.2.1 Frogfoot

Frogfoot is a system of programs and interlinked servers developed and set up to allow for very large geographical coverage of high-resolution wind resource maps, with inclusion of changing large-scale wind forcing and microscale flow effects. The core components of the Frogfoot system are:

- Terrain Service
- Climate Service
- Job Service
- Results Service
- WAsP Worker

Ancillary components are:

- Job Management Console
- Climate Data Manager
- Results Exporter

The core components are essential to carry out a Frogfoot calculation. The ancillary components are needed to set-up the configuration of a Frogfoot job, as well as import and export data into or out of the system.

The framework of Frogfoot can be understood by considering the elements required to carry out a WAsP calculation of a predicted wind climate at a single location. These elements are: the generalized wind climate data, roughness and orography data (in the form of maps) for the area around the location of interest, and flow models inside the WAsP software. The roughness and orography data is used by the flow models to determine flow effects at the location, and these flow effects are used to modify the generalized wind climate. These elements are also represented in the Frogfoot core components, see Fig. 5.3↓. For Frogfoot though, instead of considering a single point, the Job service dispatches a very large number of points within an area of interest to be calculated.

For any particular application of Frogfoot, the Job Service is set up by the Job Management Console. Here the user specifies the map data to be used, selected from map data inside the Terrain Service. Here the user also specifies the generalized wind climate data to be used, selected from generalized wind climate data inside the Climate service. The generalized wind climate data consists of a number of geo-referenced WAsP generalized wind climate files. Within the Job Management Console the definition of the area to be calculated is specified, by a map containing a single closed contour outlining the boundary of the calculation area. The user also needs to set the grid spacing and origin of the calculation nodes. The Job Management Console will then split the job into a number of tiles which are 10×10 calculation nodes in size (i.e. 100 calculation nodes in all). A tile makes up a set of calculations that will be dealt with separately by distribution of the tile to a WAsP Worker. The WAsP Worker is a standalone installation of the WAsP flow models, without the user interface. In order for the WAsP Worker to calculate the predicted wind climate at the 100 nodes, tile maps of roughness and orography are prepared by the Terrain Service. The maps are given an extent sufficient for the tile by extending the map boundary with a 25 km buffer around the extent of the tile.

The calculation also needs generalized wind climate data. This is provided by the Climate Service in the form of 100 LIB files (one for each calculation node). For each calculation node a LIB file is calculated by the Climate Service based on an interpolation of the 3 nearest LIB files from the selected generalized wind climate dataset. The interpolation weighting of the LIB files is inversely proportional to distance. For each direction sector the wind speed distribution is calculated, based on the weighted combination of the Weibull distributions for the 3 nearest LIB files, then with this a new Weibull fit is performed to provide the Weibull parameters for the interpolated LIB file.

Figure 11 below shows how the different components are related to each other and the flow of data from one component to the next. The Job Service feeds tile data to the WAsP workers. The WAsP workers are installed on computers within the same local area network as the Frogfoot servers. Once the WAsP worker has finished the calculations for one tile, the tile results are sent to the Results Service. The Job Management Console allows users to get an overview of the current jobs running on the system, as well as jobs that have been completed or paused. Once the Frogfoot job has completed, the Result Exporter is used by the user to export output in the desired format for subsequent analysis or plotting.

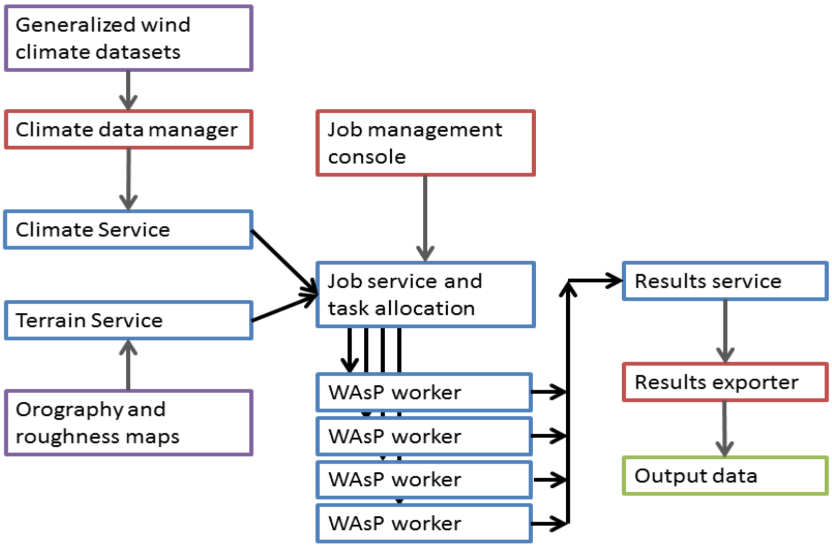

Figure 11. Schematic diagram showing the relationship and flow of data between the components of the Frogfoot system. Blue boxes represent core components of Frogfoot, red boxes represent ancillary components, purple boxes represent data that is input into the system, and the green box represents the result outputs.

The generalized wind climate data sets are described in Chapter 4 below; the orography and roughness maps in the sections below.

3.2.2 Topographical inputs

The topographical inputs for the microscale flow modelling and data handling and display are: terrain elevation, land cover and provincial boundaries. These inputs are of the same types as were used in previous detailed wind resource maps (Mortensen et al., 2014c), but updated to present day status and quality. The inputs are described briefly below.

Elevation

Terrain elevation is given in raster format, as elevation grids with a horizontal resolution of 100 m between terrain spot heights given in metres above sea level, see Figure 12. The elevations were derived from Shuttle Radar Topography Mission data designated SRTM+, NASA version 3. The SRTM Plus data were downloaded from NASA's Land Processes Distributed Active Archive Center (LP DAAC) located at the USGS Earth Resources Observation and Science (EROS) Center.

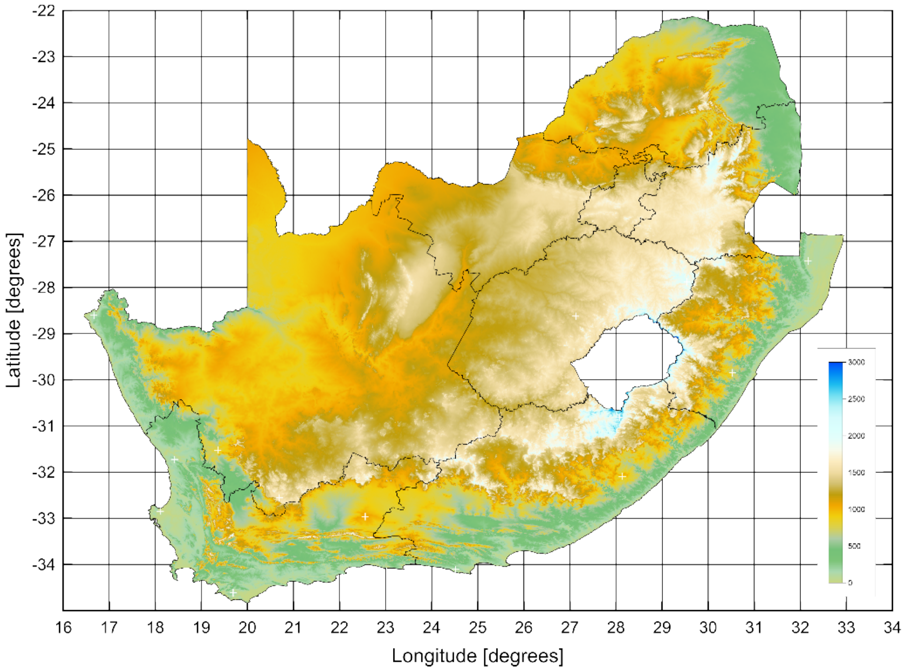

Figure 12. Elevation map of South Africa.

SRTM Plus elevations are given in a regular grid of latitude and longitude, with a spacing of three arc-seconds. Since the flow modelling is done in a metric Cartesian coordinate system, UTM WGS84, the raw data were transformed to either UTM zone 34S (NC, WC) or 35S (EC, FS, GT, LP, MP, NL, NW) and resampled to 100 m spacing using the *triangulation with linear interpolation* method in Surfer 12.

The SRTM Plus data set has been used for microscale flow modelling in all WASA activities so far and has been found to be adequate for this purpose (Mortensen et al., 2014b).

Land cover

Terrain land cover is also given in raster format, as land cover and roughness length grids with a horizontal resolution of 300 m between terrain spot roughness lengths given in metres, see Figure 13. The land cover was derived from ESA GlobCover 2009 (Bontemps *et al*., 2011). GlobCover data are © ESA 2010 and UCLouvain; see the ESA DUE GlobCover website.

GlobCover land cover codes are given in a regular grid of latitude and longitude, with a spacing of ten arc-seconds. Since the flow modelling is done in a metric Cartesian coordinate system, UTM WGS84, the raw data were transformed to either UTM zone 34S (NC, WC) or 35S (EC, FS, GT, LP, MP, NL, NW) and resampled to 300 m spacing using the *nearest neighbour* method in Surfer 12 .

The GlobCover data set was also used for microscale flow modelling in the 2014-edition of the detailed wind resource maps for the WASA 1 domain. Its use relies on the transformation of GC land cover codes to roughness lengths in metres. For the present study, the transformation table used in 2014 has been employed, see Appendix A; in WASA 2 and 3 this transformation will be investigated further.

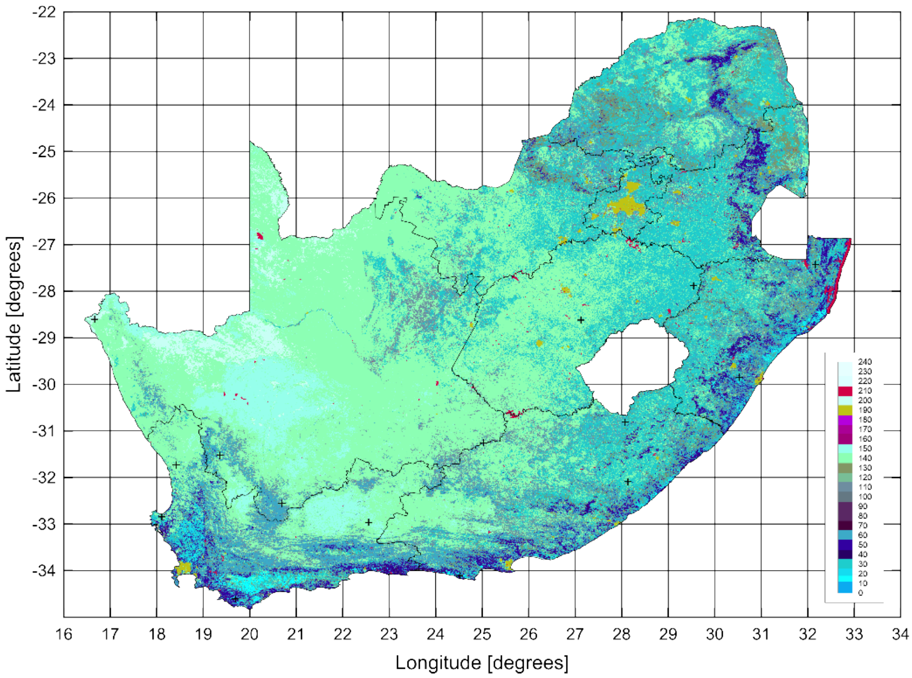

Figure 13. Land cover map of South Africa.

Boundaries

The microscale modelling and organisation of the data and results have been done for each of the nine provinces of South Africa: Eastern Cape (EC), Free State (FS), Gauteng (GT), Limpopo (LP), Mpumalanga (MP), Northern Cape (NC), KwaZulu-Natal (NL), North West (NW), and Western Cape (WC); see Figure 14.

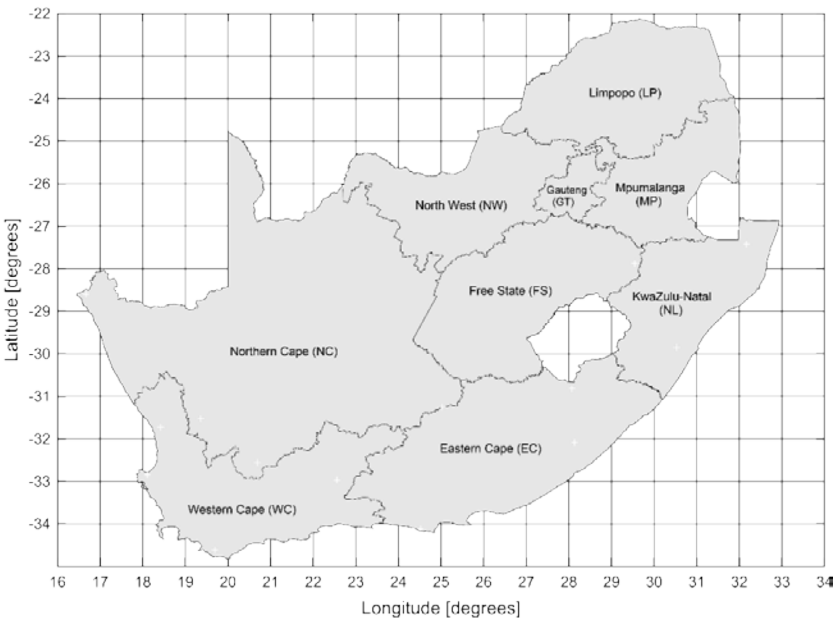

Figure 14. Provinces and boundaries of South Africa.

Present boundaries of the nine provinces have been obtained in September 2017 from the [Municipal Demarcation Board](#) (MDB); South Africa's municipal demarcation authority. The two-letter code used for each province is derived from the ISO 3166-2 standard.

3.2.3 Comparison to previous calculations

The WASA 1 domain has already been mapped in 2013 and 2014; the differences between these two detailed resource maps are given below:

Resource mapping in 2013

- Old FF engine
  - Vector map inputs
  - No air density calculations
- Wind climatologies
  - KAMM 5-km LIB files
  - comparison at 10 masts
- Elevation descriptions
  - 20-m SA 1:50,000 elevations
- Roughness length descriptions
  - GLCC roughness vector map
  - 1-km raster to vector by DTU
  - DTU translation table to roughness length values.

Resource mapping in 2014

- New FF engine
  - Raster map inputs
  - Site-specific air density model
- Wind climatologies
  - WRF 3-km LIB files
  - comparison at 10 masts
- Elevation descriptions
  - 100-m SRTM+ elevation grid
- Roughness length descriptions
  - 300-m GlobCover 2009 grid
  - DTU translation table from GC land cover to roughness length.

The present detailed interim wind resource maps were modelled as given above for 2014, but with the latest WAsP (FF) engine, updated WRF 3- and 5-km LIB files, and comparisons at all 15 WASA 1 and 2 masts. In addition, the maps now cover all of South Africa.

3.2.4 Setting up the national calculation

For practical purposes, the calculation of South Africa was done province by province for the nine provinces. For Northern Cape (NC) and Western Cape (WC) provinces, the Universal Transverse Mercator (UTM) projection (zone 34) has been used, with the World Geodetic System (WGS) 1984 datum. The coordinate system is thus referred to as **UTM 34S WGS84**.

For Eastern Cape (EC), Free State (FS), Gauteng (GT), Limpopo (LP), Mpumalanga (MP), Kwa-Zulu-Natal (NL), and North West (NW) provinces, zone 35 of the same system has been used. This coordinate system is thus referred to as **UTM 35S WGS84**.

Like before, the WAsP engine of Frogfoot has been employed in its default configuration. The topographical input data to the Frogfoot modelling are described above.

3.3 Validation

Validation of the modelling is done by comparing mean wind climates observed at the 10 WASA1 masts and 5 WASA2 masts with modelled mean wind climates at the same sites. In Table 3, we compare the wind resource or potential at these 15 sites; where the so-called generalised wind climate is taken to represent the ‘wind resource’.

The validation of the modelling is carried out for different time periods at the various masts, but the same period is used in the model and the observations. The periods used are as in Mortensen et al (2014b) for WASA1 and Mortensen et al (2017) for the WASA2 masts. The generalized wind climate calculation is done from the time-series of the WRF-simulated winds and stabilities using the same parameters as in Table 2. However, in WASA1 the validation is carried out for generalized winds from hourly WRF outputs, as opposed to the validation carried out for 10-minutes WRF winds at 100 m a.g.l. in Hahmann et al (2015a).

Table 3. Validation of the modelling at the WASA1 and WASA2 mast sites.

Station	Observed mean wind speed at *h*=62 m	General-ized mean wind speed at *h*=62 m z_0=3 cm	WASA1 generalized mean wind[1] *h*=62 m z_0=3 cm	WASA1 error in generalized mean wind	WASA-FT general-ized mean wind[2] *h*=62 m z_0=3 cm	WASA-FT error in general-ized mean wind
	[ms^{-1}]	[ms^{-1}]	[ms^{-1}]	[%]	[ms^{-1}]	[%]
WM01	6.07	6.12	5.66	−7	6.14	0
WM02	6.15	5.94	6.23	5	6.53	10
WM03	7.15	6.55	5.83	−11	6.12	−7
WM04	6.69	6.68	6.64	−1	6.74	1
WM05	8.63	8.10	7.44	−8	7.63	−6
WM06	7.31	7.05	7.09	1	7.80	11
WM07	6.95	6.92	6.22	−10	6.88	−1
WM08	7.38	7.18	7.19	0	7.13	−1
WM09	8.16	7.48	7.64	2	7.72	3
WM10	6.58	6.36	6.67	5	6.91	9
Mean (WM01-WM10)				−2.5		2.0
WM11	7.52	6.21			7.20	16
WM12	5.00	4.97			5.47	10
WM13	5.21	5.24			6.13	17
WM14	7.45	6.87			7.22	5
WM15	6.10	5.78			5.25	−9
Mean (WM11-WM15)						7.8
Mean (WM01-WM15)						4.2

For WASA1 3-km modelling, the average difference between modelled and measured winds at the 10 WASA1 mast sites is −2.5% with a mean absolute percentage error (MAPE) of +5.0%.

For the Fast-track (FT) 5-km modelling, the average difference between modelled and measured winds at the 10 mast sites is 2.0% with a mean absolute percentage error of +4.7%.

For the WASA2 mast sites, the average wind speed differences are significantly larger; with a mean absolute percentage error of about +11%. However, these results may improve when more data are collected at these sites and the analysis of the topography and atmospheric characteristics have been finalised as part of WASA2.

[1] WASA1 simulation at WASA1 masts, hourly data

[2] WASA3 (Fast-Track) simulation at WASA2 masts, 20-minute data

4. Wind-climatology – mesoscale modelling

In this chapter, we show the wind climates simulated by the WRF model; for the 3-km (Figure 15), 5-km (Figure 16) and 15-km domains (Figure 17). These simulated wind climates are input to the DTU Generalisation procedure, which will result in generalised wind climates – these were shown in Chapter 2.

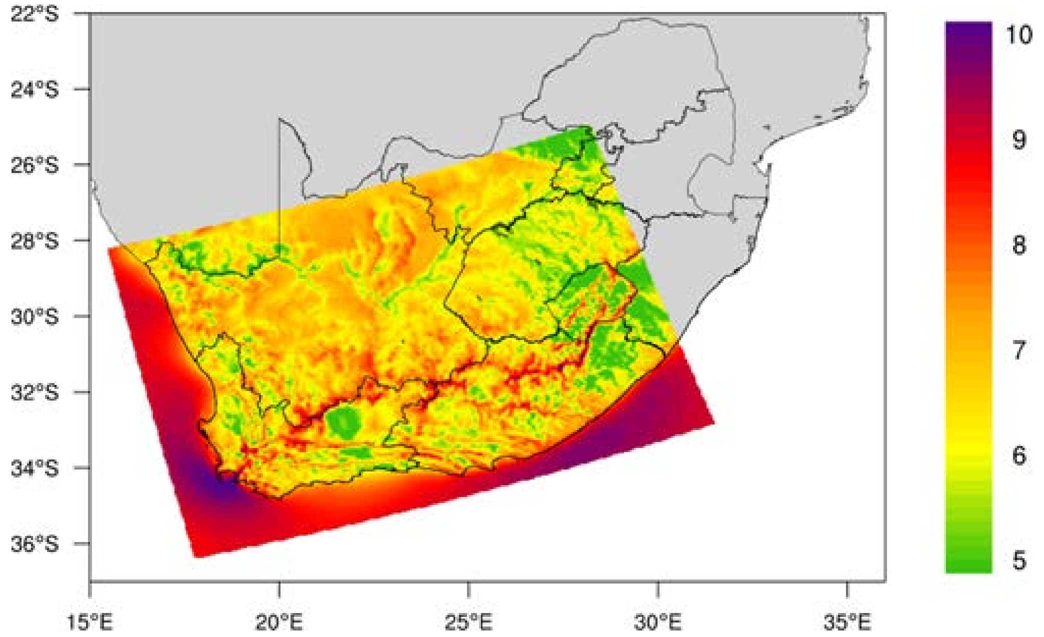

Figure 15. Mean wind speed (ms^{-1}) simulated by the WRF model at 100 m a.g.l. For the period 1 October 2005 to 30 September 2013 for WASA 1 (3 km×3 km).

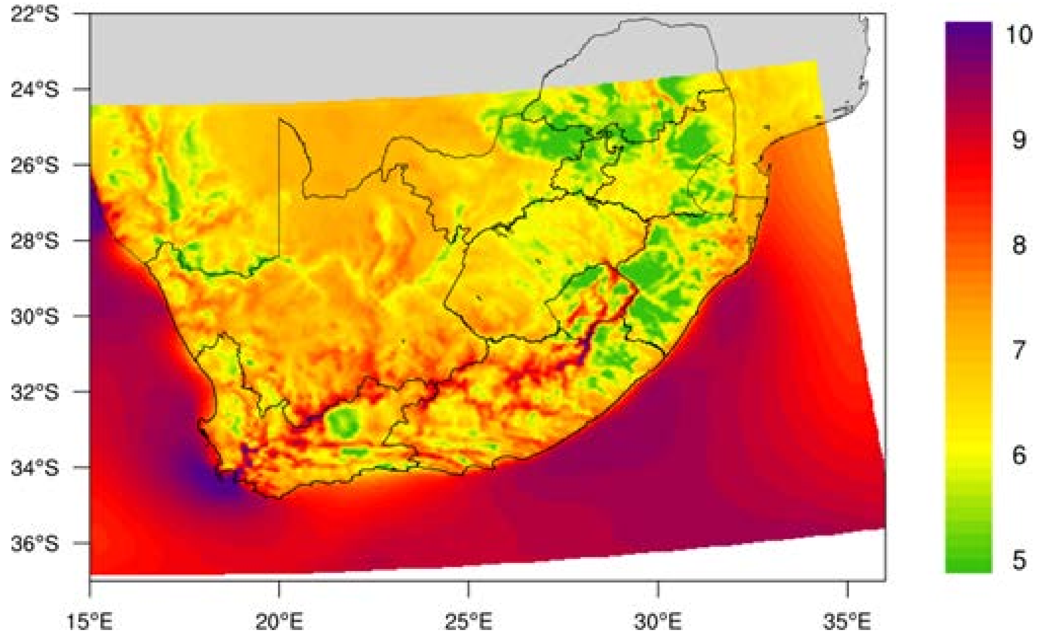

Figure 16. Mean wind speed (ms^{-1}) simulated by the WRF model at 100 m a.g.l. For the period 1 October 2005 to 30 September 2013 for WASA 2 (5 km×5 km).

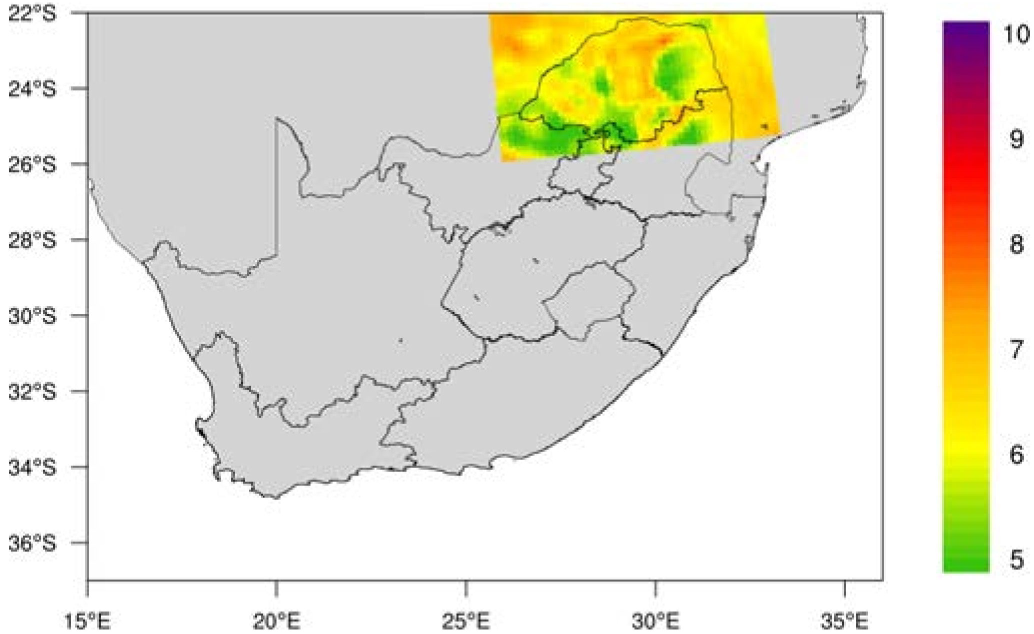

Figure 17. Mean wind speed (ms^{-1}) simulated by the WRF model at 100 m a.g.l. For the period 1 October 2005 to 30 September 2013 for WASA 2 (15 km×15 km) domain.

5. Summary and conclusions

The present report describes the work carried out and the results obtained in during the *WP 34.01x WASA 3 DEA SEA Fast Track (DTU)* component of the WASA3 project. The entire land area of South Africa has been modelled with a system of mesoscale and microscale models, in order to obtain the first realistic estimate of South Africa's wind resources. Compared to WASA Phase 1 modelling, the area covered here is more than 3.5 times larger.

The modelling procedures have also been improved since the WASA 1 domain was modelled in 2014; in particular the DTU Generalisation procedure and WAsP Resource Mapping System. In addition, the modelling is now based on the WASA 1 temporal coverage (Oct 2005 to Sep 2013 = 9 y) for the wind climatologies in comparison to the DEA SEA Phase 1 temporal coverage of only 4 years (2009 to 2013). The topographical input data – 100-m elevation grids and 300-m land cover (roughness length) grids – are similar to the WASA 1 modelling, but cover the entire country.

The results of the modelling have been vastly extended and improved compared to WASA 1. Detailed wind resource maps in GIS-compatible format now exist for all of South Africa, not only for 100 m a.g.l., but also for 50 and 200 m a.g.l. In addition to these data sets, comprehensive results are provided for all 250-m modelling nodes at three modelling heights: Weibull *A*- and *k*-parameters and the frequencies of occurrence (wind rose) for 12 sectors. These data sets make it possible to calculate additional statistics for all of South Africa; e.g. specific mean power density from 0-25 ms^{-1}, energy yield for any given wind turbine, capacity factors, etc.

Finally, the wind-climatological inputs to the microscale modelling are also provided, in the form of WAsP LIB files for every mesoscale modelling node. These generalised wind climates make it possible to perform detailed calculations anywhere in South Africa, e.g. for wind farm project planning and design of measurement campaigns. However, it must be stressed that the results obtained here do not replace the detailed measurements required for wind farm planning and development; they just add to the quality that can be obtained.

It should be borne in mind that the validation of the modelling does not have the same quality in all parts of South Africa. In the WASA 1 domain, the validation is based on long time-series of high-quality wind data, in an area of South Africa that is well described and analysed; whereas the measurements and analyses are still going on in the WASA 2 domain. For the rest of South Africa, no validation data were available at the time of writing and the terrain and weather have not been studied in the same detail.

The metadata documents given in Appendix B (for WASA 1 domain) and C (for South Africa) provide further information on the data sets: the purpose, methodology, limitations and some additional information available at the WASA download web site.

The work reported here will continue in Phase 2 and 3 of the WASA project, in the years 2018-20. During the work, it has become apparent how important e.g. the land cover descriptions and atmospheric stability are for the modelling. These are two topics that will be studied further, in order to obtain the best possible updated wind resource maps at the end of WASA Phase 3.

Acknowledgements

WASA team for provision of wind-climatological and topographical data. WAsP development teams at DTU Wind Energy and World in a Box Oy for Frogfoot development and application. SRTM Plus data were downloaded from NASA's Land Processes Distributed Active Archive Center (LP DAAC) located at the USGS Earth Resources Observation and Science (EROS) Center. GlobCover data are © ESA 2010 and UCLouvain; see the ESA DUE GlobCover website. Province boundaries by Municipal Demarcation Board (MDB).

The Wind Atlas for South Africa (WASA) project is an initiative of the South African Government, Department of Energy (DoE), and the project is co-funded by GEF through South African Wind Energy Programme (SAWEP) and the Royal Danish Embassy with UNDP support. The WASA Project Steering Committee has members from DoE (chair), DEA, DST, UNDP, Royal Danish Embassy, and SANEDI.

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A GlobCover land cover codes and descriptions

Value	GlobCover global legend, 23 classes	Roughness
11	Post-flooding or irrigated croplands	0.003
14	Rain fed croplands	0.01
20	Mosaic Cropland (50-70%) / Vegetation (grassland, scrubland, forest) (20-50%)	0.05
30	Mosaic Vegetation (grassland, scrubland, forest) (50-70%) / Cropland (20-50%)	0.01
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	0.03
50	Closed (>40%) broadleaved deciduous forest (>5m)	0.03
60	Open (15-40%) broadleaved deciduous forest (>5m)	0.03
70	Closed (>40%) needle-leaved evergreen forest (>5m)	0.80
90	Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)	0.80
100	Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5m)	0.80
110	Mosaic Forest/Scrubland (50-70%) / Grassland (20-50%)	0.80
120	Mosaic Grassland (50-70%) / Forest/Scrubland (20-50%)	0.80
130	Closed to open (>15%) shrub land (<5m)	0.50
140	Closed to open (>15%) grassland	0.10
150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)	0.01
160	Closed (>40%) broadleaved forest regularly flooded – Fresh water	0.01
170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded – Saline water	0.01
180	Closed to open (>15%) vegetation (grassland, shrub land, woody vegetation) on regularly flooded or waterlogged soil – Fresh, brackish or saline water	0.01
190	Artificial surfaces and associated areas (urban areas >50%)	1.00
200	Bare areas	0.01
210	Water bodies	0.00
220	Permanent snow and ice	0.003
230	No data pixel values	0.03

B Metadata for “High-Resolution Wind Resource Map for WASA 1 domain”

The next eight pages contain the original metadata document for the WASA 1 domain

DTU Wind Energy

High-Resolution Wind Resource Map for WASA 1 domain

Metadata and further information

October 2017

METADATA	
Data set name	High-Resolution Wind Resource Map for WASA 1 domain
Data set date	October 2017
Data provider	DTU Wind Energy and CSIR
Contact persons	Niels G. Mortensen (DTU) or Eugéne Mabille (CSIR)
Contact details	nimo@dtu.dk (DTU) or EMabille@csir.co.za (CSIR)
Data type	Raster data sets with a grid cell size of 250 m
Data format	ArcGIS ASC
File name(s)	ZA_<province>_<resolution>_<parameter>_<version ID>.asc
Data origin	Microscale modelling in each grid point; no interpolation

DATA PARAMETERS	
Mean wind speed	Annual mean wind speed U [ms^{-1}] @ 50, 100 and 200 m a.g.l.
Mean power density	Annual mean power density P [Wm^{-2}] @ 50, 100 and 200 m a.g.l.
Terrain elevation	Elevation of modelling site in [m] above mean sea level
Ruggedness index RIX	Site RIX value calculated by WAsP (standard parameter setup)

COORDINATE SYSTEM	
Projection	Universal Transverse Mercator (UTM)
Zone number	34S (two provinces) and 35S (one province)
Datum	World Geodetic System 1984 (WGS 84)

TECHNOLOGY	
Calculation software	WAsP Resource Mapping System with WAsP engine version 11
Wind-climatological input	3-km NWA (WRF-based, code name SAC-3km-LARGE)
Elevation data input	100-m elevation grid derived from SRTM+ (NASA version 3)
Roughness data input	300-m land cover grid derived from GlobCover 2009 (version 2.3)
Air density input	Standard atmosphere approximation w/ elevation variations only

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NOTES

Purpose

This data set was created for the Department of Environmental Affairs (DEA) of South Africa as a *Fast-track High-resolution Wind Resource Map and Database covering all of South Africa*. The wind resource maps were designed specifically for inclusion in GIS-based strategic environmental assessments (SEA) for the entire land mass of South Africa. The maps cover the Wind Atlas for South Africa, Phase 1 modelling domain. The Wind resource maps are subject to change without notice if and when more accurate and reliable data, models and procedures become available.

Methodology

Reference is made to the information and documentation available from www.wasa.csir.co.za. A more detailed description of the data sets available are given at the end of this document. Validation is reported elsewhere.

Limitations

The data set is limited by the operational envelopes of the wind atlas methodology and the WAsP models. The accuracy depends on a) the accuracy of the VNWA, which has been validated against the data from 10 WASA measurement masts, b) the WAsP microscale modelling and c) the input topographical data.

In complex terrain (RIX > 5%), the wind resources may be significantly over-estimated by the WAsP microscale modelling. Above and close to built-up areas like cities, towns and villages, the results are less reliable. Close to and above forested areas, the results are also less reliable and should be interpreted and used accordingly.

The data set was designed specifically for planning purposes and should be used with utmost care for design, development and detailed assessments of actual wind farms; where local, on-site measurements are strongly recommended.

Available documentation

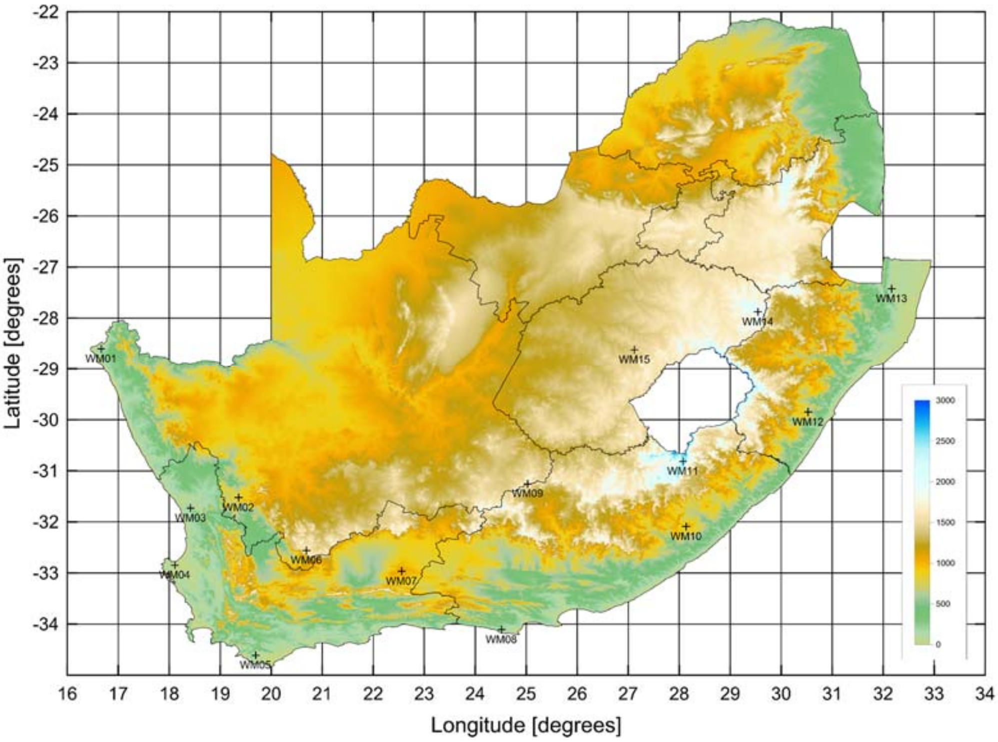
The wind atlas methodology is described in the European Wind Atlas (1989); the application of WAsP in the software documentation, see www.wasp.dk. The Validated Numerical Wind Atlas (VNWA) for South Africa is a product of the Wind Atlas for South Africa project (WASA) and is described on the WASA download pages.

Acknowledgements

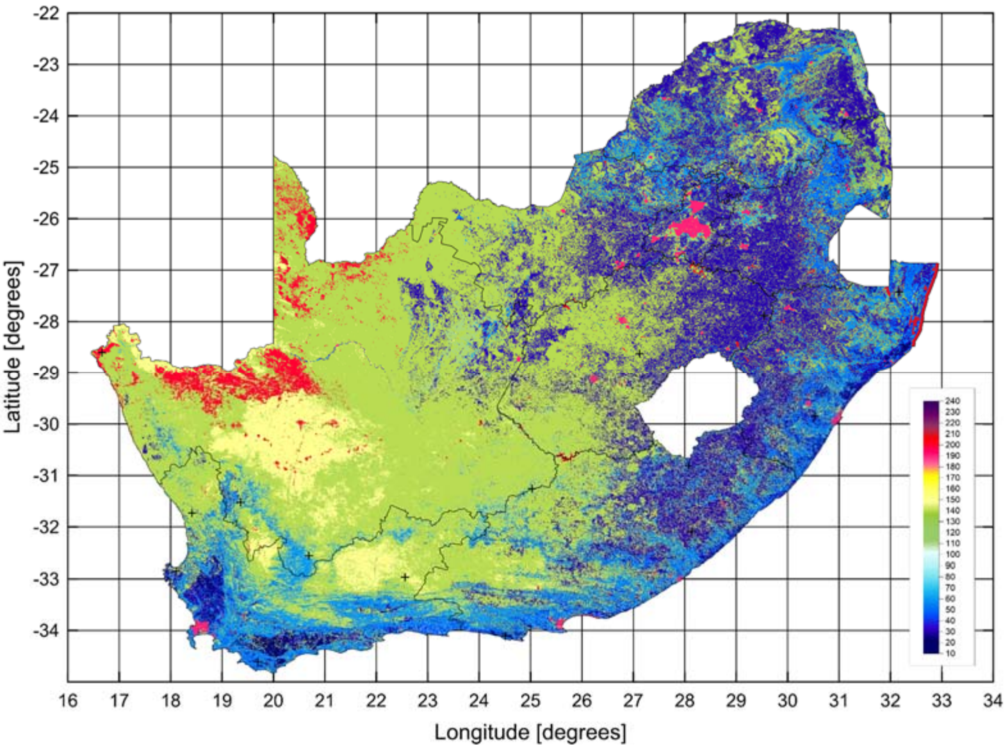
WASA team for provision of wind-climatological and topographical data. WAsP development teams at DTU Wind Energy and World in a Box Oy for Frogfoot development and application. SRTM Plus data were downloaded from NASA's Land Processes Distributed Active Archive Center (LP DAAC) located at the USGS Earth Resources Observation and Science (EROS) Center. GlobCover data are © ESA 2010 and UCLouvain, see the ESA DUE GlobCover website. Province boundaries by Municipal Demarcation Board (MDB).

DISCLAIMER

South Africa terrain elevation (SRTM+, NASA version 3)



South Africa land cover (GlobCover version 2.3, 2009)



Detailed wind resource maps

The data sets are organised according to each of the three provinces which were part of the WASA 1 domain (Wind Atlas for South Africa, Phase 1):

- Western Cape (WC)
- Eastern Cape (EC)
- Northern Cape (NC)

For each province, the following information is provided in metric ArcGIS ASC format grid files:

- Mean wind speed [ms^{-1}]
- Mean power density [Wm^{-2}]
- Terrain surface elevation [m a.s.l.]
- Terrain ruggedness index, RIX

Wind information given for 50, 100 and 200 m above ground level and all data sets are given at 250 m horizontal resolution. The ASC files are distributed in ZIP archives.

Database of wind climates

For each province, the following information is provided in ASCII TXT format files:

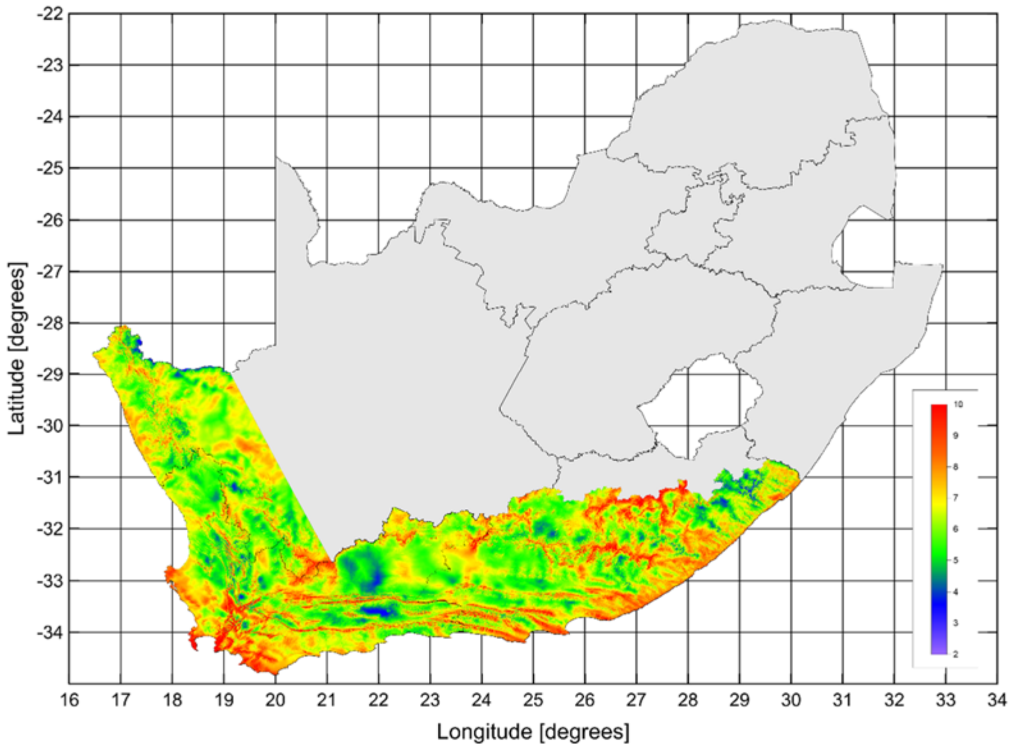
- Weibull *A*- and *k*-parameters for 12 sectors at each node and height
- Wind direction distribution (rose) for 12 sectors at each node and height

Climate information at each of the 250-m modelling grid points will make it possible to calculate, say, specific mean power density from 0-25 ms^{-1}, energy yield for any given wind turbine, capacity factor for any given wind turbine, etc. Wind climate and energy information is given for 50, 100 and 200 m above ground level. Data are stored in ASCII text files with the following format:

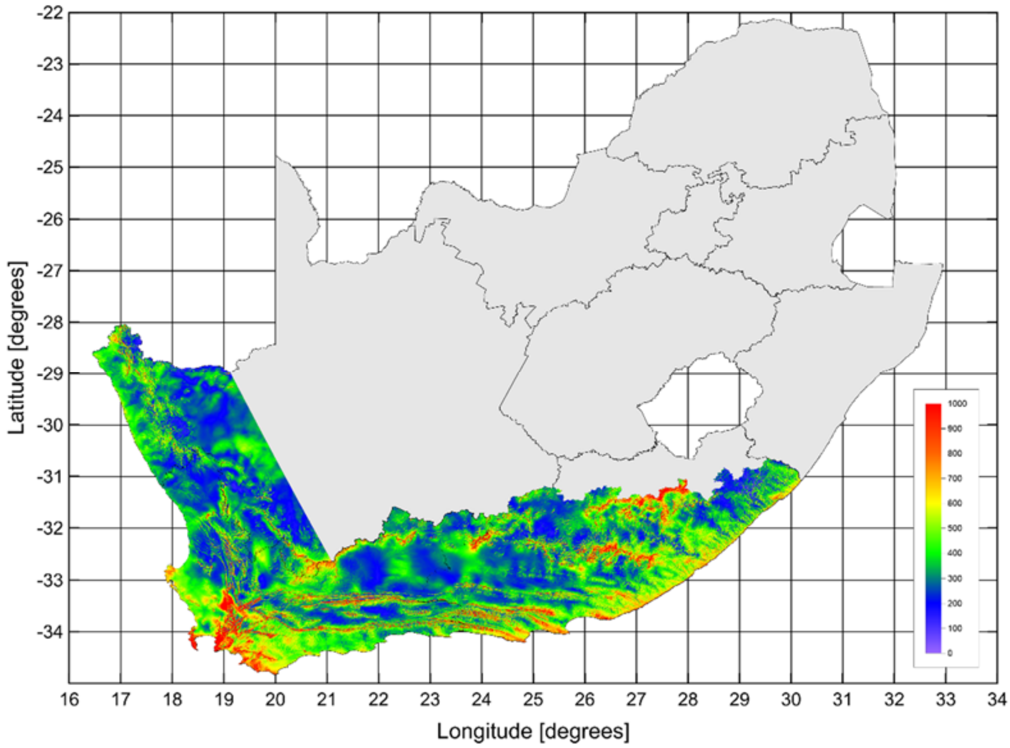
- *JobID; x; y; z; SectorIndex; A; k; f;*

where *x* is UTM Easting [m], *y* is UTM Northing [m], *z* is height above ground level [m], *SectorIndex* is a sector index from 1 to 12 clockwise starting from north, *A* is Weibull scale parameter [ms^{-1}], *k* is the Weibull scale parameter, and *f* is sector frequency. The TXT files are distributed in ZIP archives.

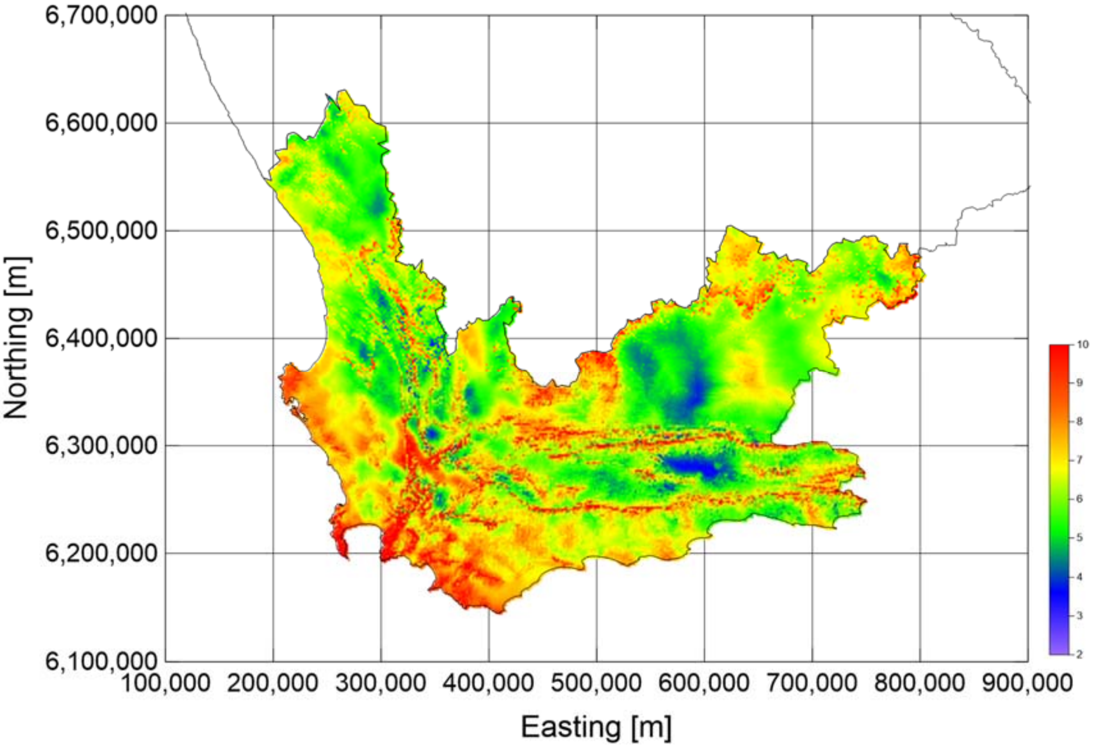
WASA1 mean wind speed at 100 m a.g.l.



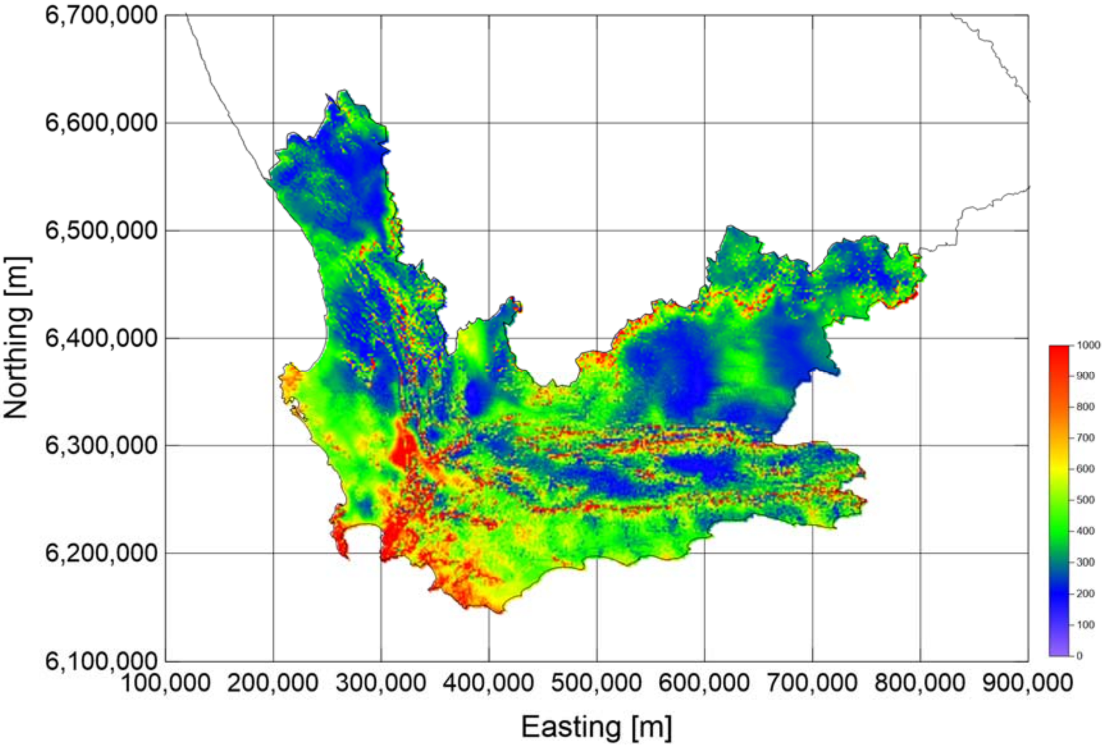
WASA1 mean power density at 100 m a.g.l.



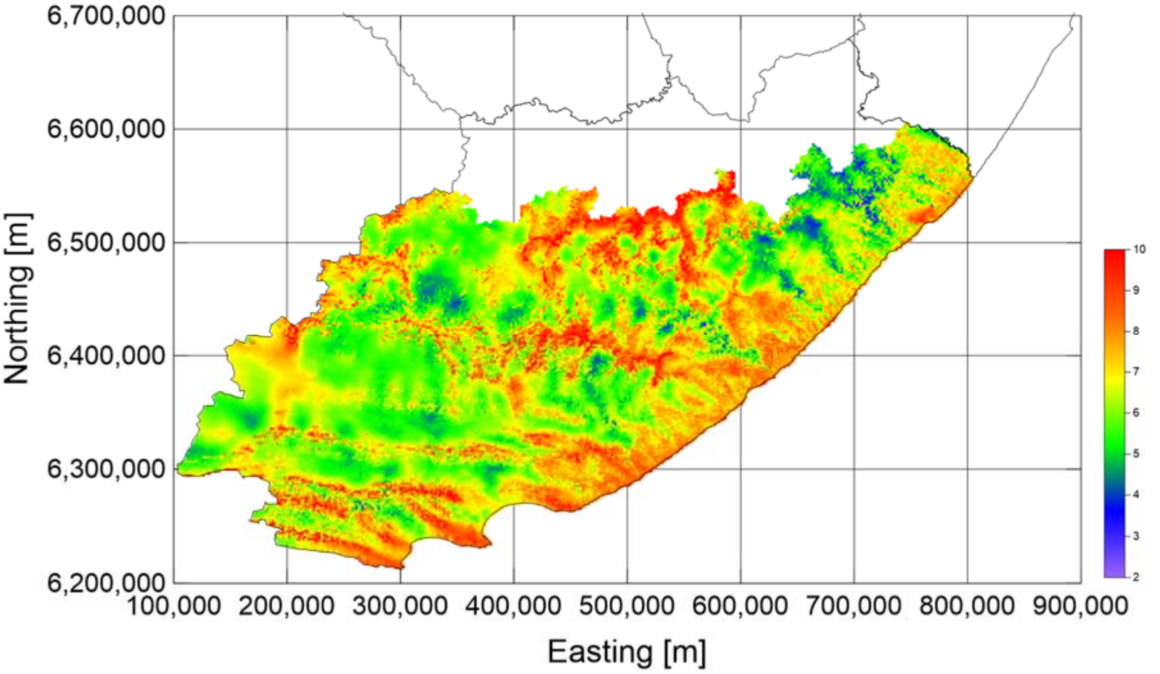
Western Cape mean wind speed at 100 m a.g.l. (WASA 1 domain only)



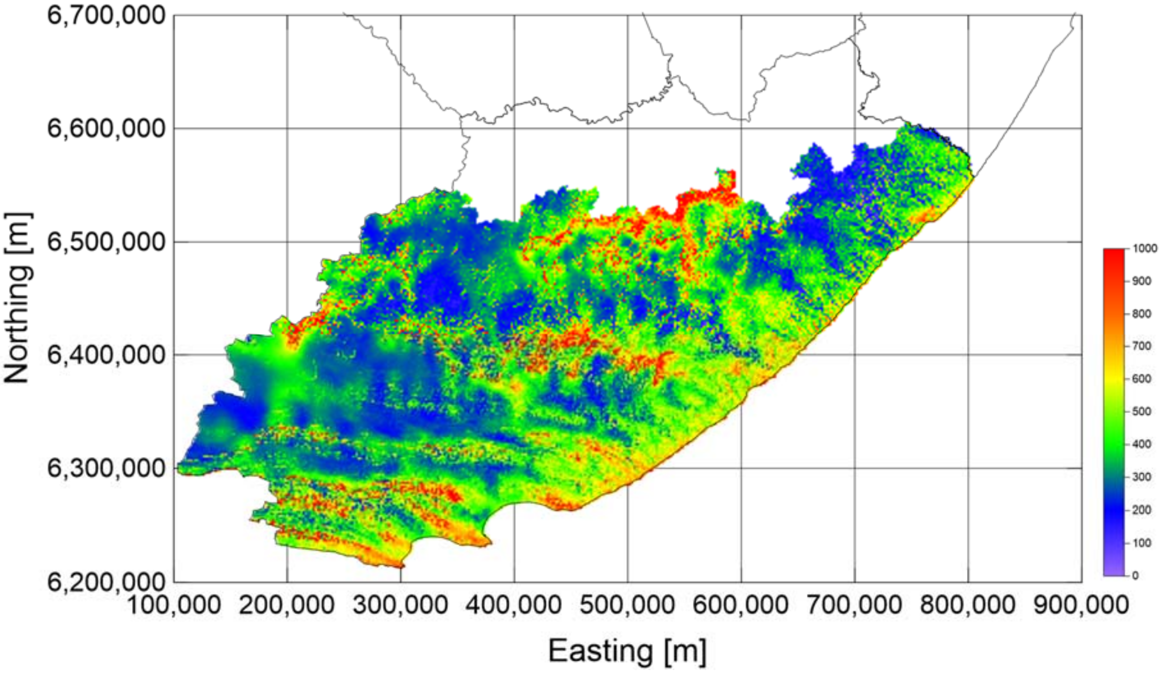
Western Cape mean power density at 100 m a.g.l. (WASA 1 domain only)



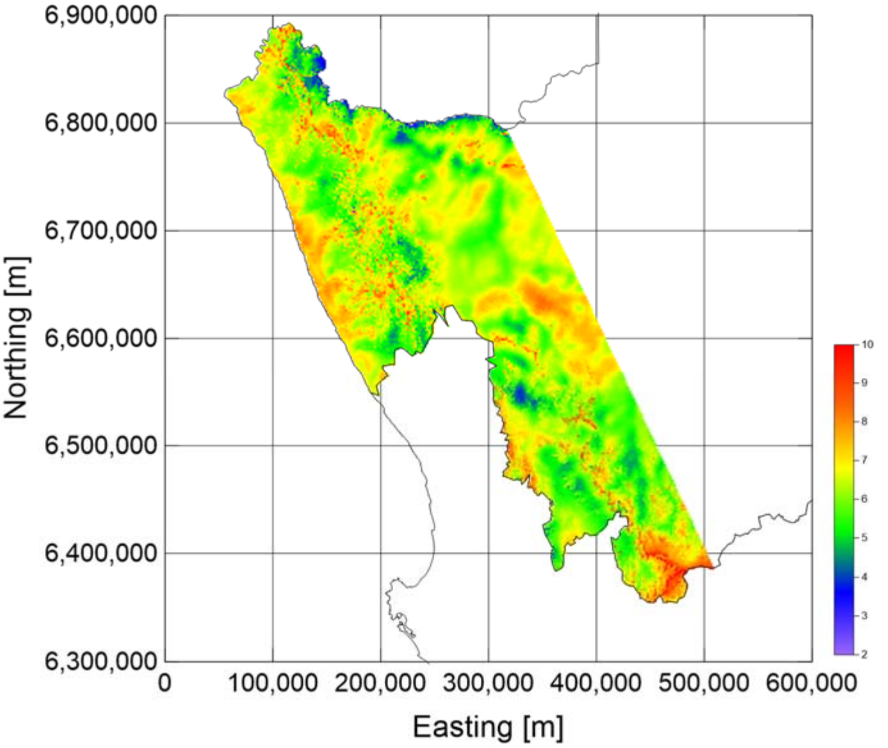
Eastern Cape mean wind speed at 100 m a.g.l. (WASA 1 domain only)



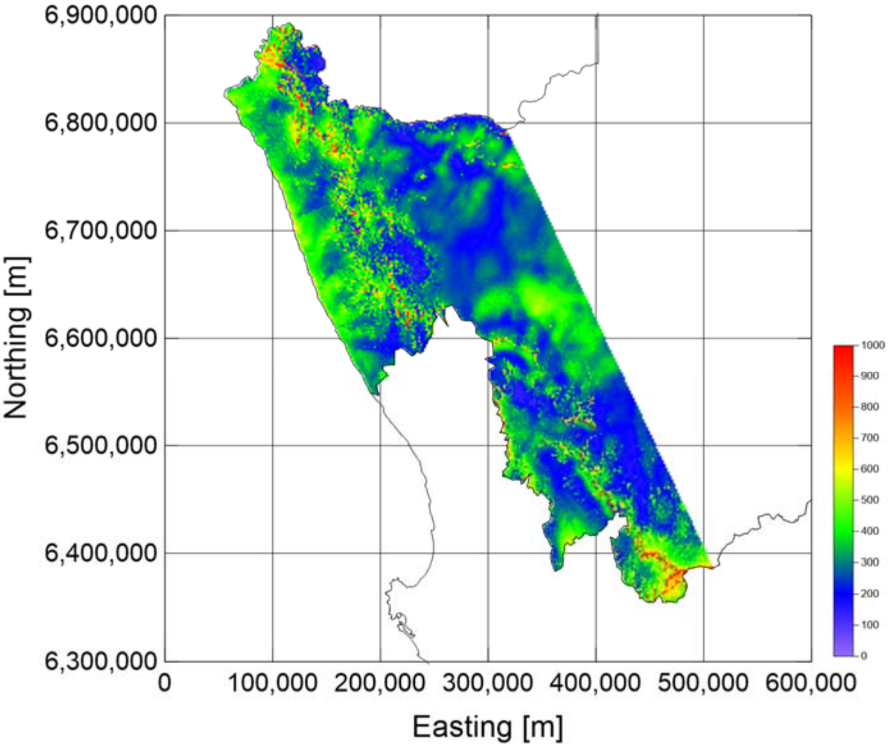
Eastern Cape mean power density at 100 m a.g.l. (WASA 1 domain only)



Northern Cape mean wind speed at 100 m a.g.l. (WASA 1 domain only)



Northern Cape mean power density at 100 m a.g.l. (WASA 1 domain only)



C Metadata for “Interim High-Resolution Wind Resource Map for South Africa”

The next 13 pages contain the original metadata document for all of South Africa

Interim High-Resolution Wind Resource Map for South Africa

Metadata and further information

October 2017

METADATA	
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Data set date	October 2017
Data provider	DTU Wind Energy and CSIR
Contact persons	Niels G. Mortensen (DTU) or Eugéne Mabille (CSIR)
Contact details	nimo@dtu.dk (DTU) or EMabille@csir.co.za (CSIR)
Data type	Raster data sets with a grid cell size of 250 m
Data format	ArcGIS ASC
File name(s)	ZA_<province>_<resolution>_<parameter>_<version ID>.asc
Data origin	Microscale modelling in each grid point; no interpolation

DATA PARAMETERS	
Mean wind speed	Annual mean wind speed *U* [ms^{-1}] @ 50, 100 and 200 m a.g.l.
Mean power density	Annual mean power density *P* [Wm^{-2}] @ 50, 100 and 200 m a.g.l.
Terrain elevation	Elevation of modelling site in [m] above mean sea level
Ruggedness index RIX	Site RIX value calculated by WAsP (standard parameter setup)

COORDINATE SYSTEM	
Projection	Universal Transverse Mercator (UTM)
Zone number	34S (two provinces) and 35S (seven provinces)
Datum	World Geodetic System 1984 (WGS 84)

TECHNOLOGY	
Calculation software	WAsP Resource Mapping System with WAsP engine version 11
Wind-climatological input	5-km NWA (WRF-based, code name WASA2-MYN-NOAH-10D)*
Elevation data input	100-m elevation grid derived from SRTM+ (NASA version 3)
Roughness data input	300-m land cover grid derived from GlobCover 2009 (version 2.3)
Air density input	Standard atmosphere approximation w/ elevation variations only

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NOTES

Purpose

This data set was created for the Department of Environmental Affairs (DEA) of South Africa as a *Fast-track High-resolution Wind Resource Map and Database covering all of South Africa*. The wind resource maps were designed specifically for inclusion in GIS-based strategic environmental assessments (SEA) for the entire land mass of South Africa. The maps cover 9 provinces and an area of about 1,221,000 km^2. Wind resource maps are preliminary and subject to change without notice if and when more accurate and reliable data, models and procedures become available.

Methodology

Reference is made to the information and documentation available from www.wasa.csir.co.za. A more detailed description of the data sets available are given at the end of this document. Validation is reported elsewhere.

Limitations

The data set is limited by the operational envelopes of the wind atlas methodology and the WAsP models. The accuracy depends on a) the accuracy of the VNWA, which has been validated against the data from 10 WASA measurement masts, b) the WAsP microscale modelling and c) the input topographical data.

In complex terrain (RIX > 5%), the wind resources may be significantly over-estimated by the WAsP microscale modelling. Above and close to built-up areas like cities, towns and villages, the results are less reliable. Close to and above forested areas, the results are also less reliable and should be interpreted and used accordingly.

The data set was designed specifically for planning purposes and should be used with utmost care for design, development and detailed assessments of actual wind farms; where local, on-site measurements are strongly recommended.

Available documentation

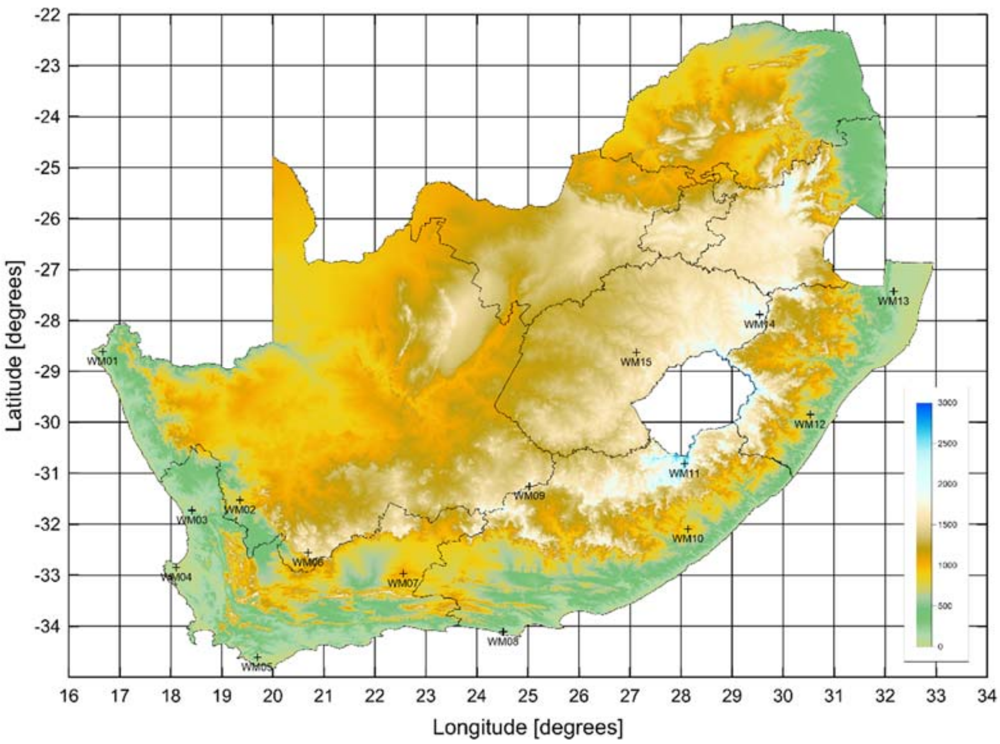
The wind atlas methodology is described in the European Wind Atlas (1989); the application of WAsP in the software documentation, see www.wasp.dk. The Validated Numerical Wind Atlas (VNWA) for South Africa is a product of the Wind Atlas for South Africa project (WASA) and is described on the WASA download pages.

Acknowledgements

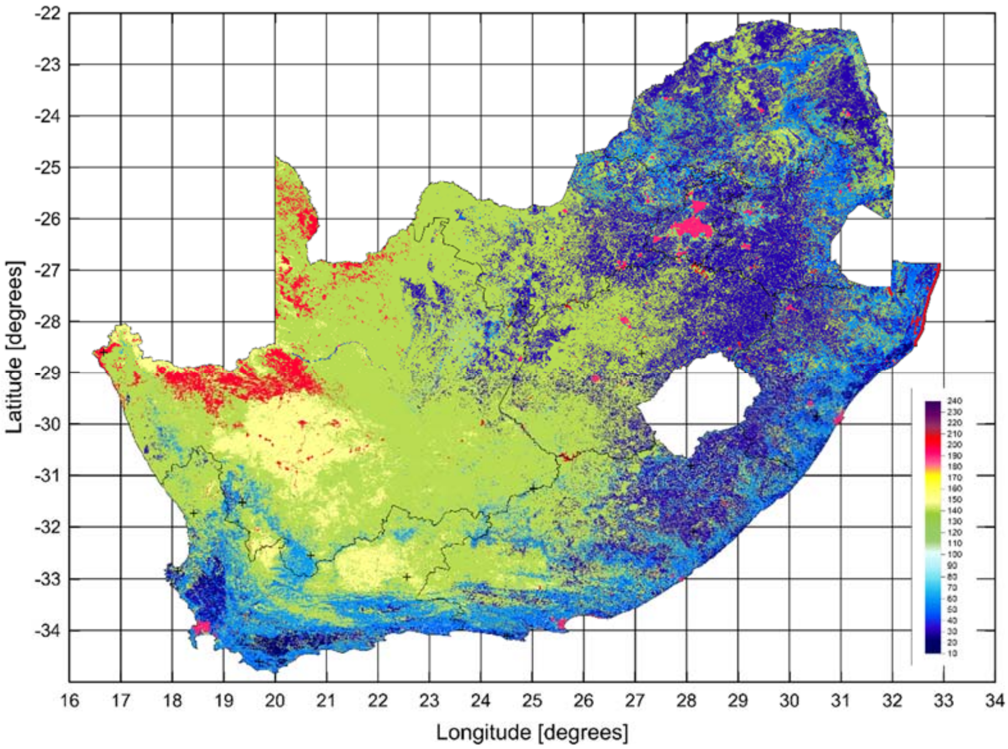
WASA team for provision of wind-climatological and topographical data. WAsP development teams at DTU Wind Energy and World in a Box Oy for Frogfoot development and application. SRTM Plus data were downloaded from NASA's Land Processes Distributed Active Archive Center (LP DAAC) located at the USGS Earth Resources Observation and Science (EROS) Center. GlobCover data are © ESA 2010 and UCLouvain, see the ESA DUE GlobCover website. Province boundaries by Municipal Demarcation Board (MDB).

**Wind climatologies for Limpopo north of 24 degrees south are given at a resolution of 15 km.*

South Africa terrain elevation (SRTM+, NASA version 3)



South Africa land cover (GlobCover version 2.3, 2009)



Detailed wind resource maps

The data sets are organised according to each of the nine provinces of South Africa.

ISO	Province	Capital	Area	Fraction	UTM
EC	Eastern Cape	Bhisho (Bisho)	168,966 km^2	14%	35
FS	Free State	Bloemfontein	129,825 km^2	11%	35
GT	Gauteng	Johannesburg	18,178 km^2	1%	35
LP	Limpopo	Polokwane (Pietersburg)	125,754 km^2	10%	35
MP	Mpumalanga	Nelspruit	76,495 km^2	6%	35
NC	Northern Cape	Kimberley	372,889 km^2	31%	34
NL	KwaZulu-Natal	Pietermaritzburg	94,361 km^2	8%	35
NW	North West	Mahikeng (Mafikeng)	104,882 km^2	9%	35
WC	Western Cape	Cape Town	129,462 km^2	11%	34
ZA	Republic of South Africa	Pretoria, Cape Town, Bloemfontein	1,220,813 km^2	100%	

For each province, the following information is provided in metric ArcGIS ASC format grid files:

- Mean wind speed [ms^{-1}]
- Mean power density [Wm^{-2}]
- Terrain surface elevation [m a.s.l.]
- Terrain ruggedness index, RIX

Wind information given for 50, 100 and 200 m above ground level and all data sets are given at 250 m horizontal resolution. The ASC files are distributed in ZIP archives.

Database of wind climates

For each province, the following information is provided in ASCII TXT format files:

- Weibull *A*- and *k*-parameters for 12 sectors at each node and height
- Wind direction distribution (rose) for 12 sectors at each node and height

Climate information at each of the 250-m modelling grid points will make it possible to calculate, say, specific mean power density from 0-25 ms^{-1}, energy yield for any given wind turbine, capacity factor for any given wind turbine, etc. Wind climate and energy information is given for 50, 100 and 200 m above ground level. Data are stored in ASCII text files with the following format:

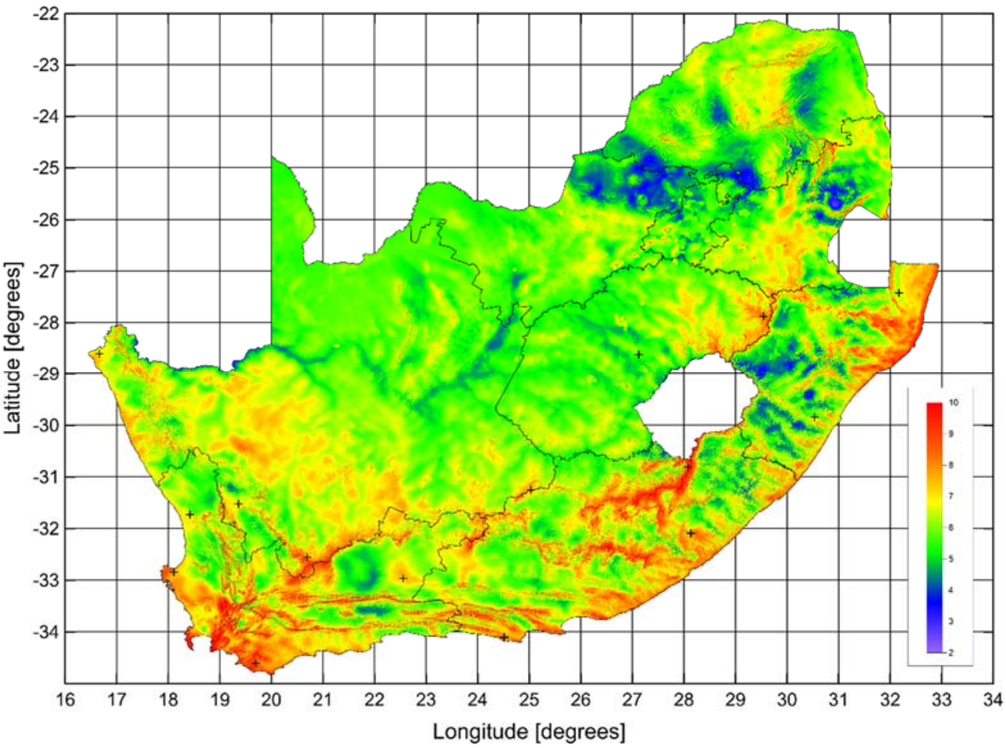
- *JobID; x; y; z; SectorIndex; A; k; f;*

where *x* is UTM Easting [m], *y* is UTM Northing [m], *z* is height above ground level [m], *SectorIndex* is a sector index from 1 to 12 clockwise starting from north, *A* is Weibull scale parameter [ms^{-1}], *k* is the Weibull scale parameter, and *f* is sector frequency. The TXT files are distributed in ZIP archives.

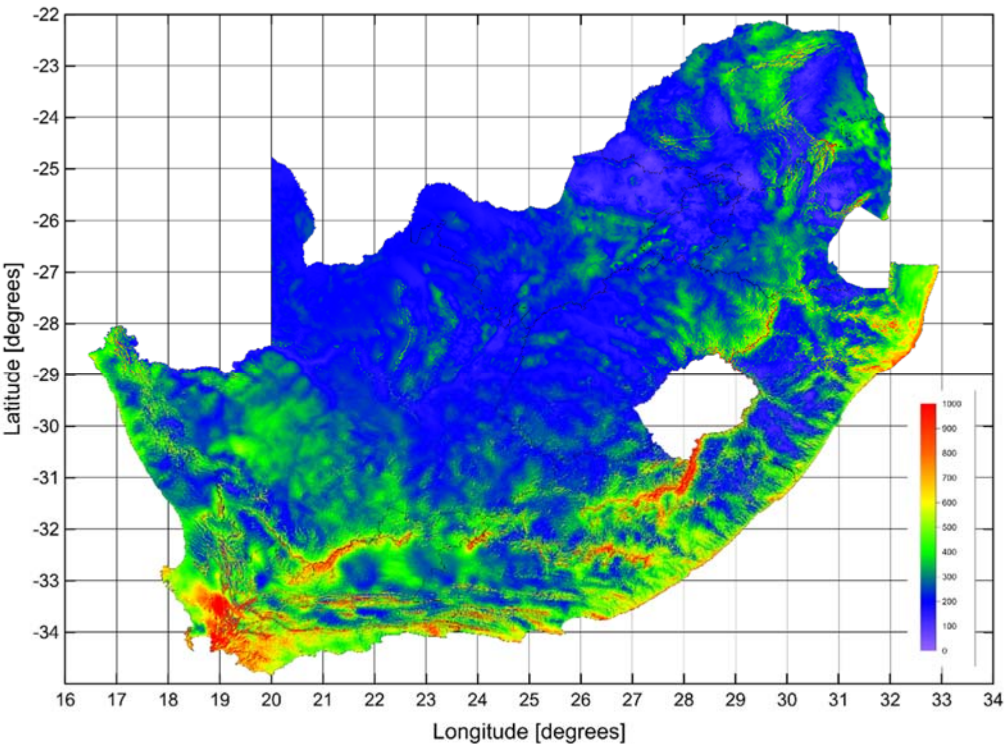
For South Africa, the following information is provided in geographical ArcGIS ASC format grid files:

- Terrain land cover classification code (GlobCover 2009)
- Transformation table from land cover to terrain surface roughness in [m]

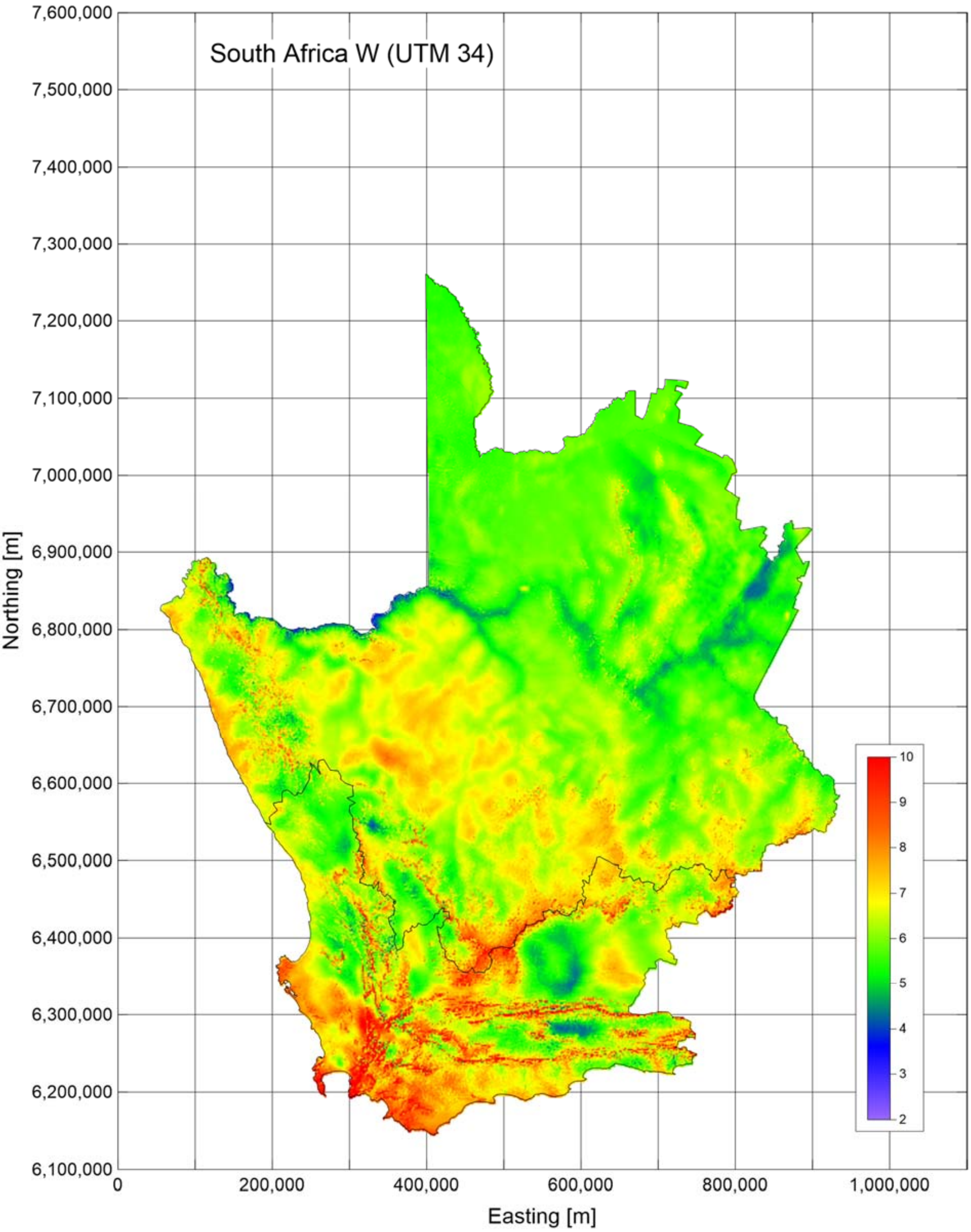
South Africa mean wind speed [ms^{-1}] @ 100 m a.g.l.



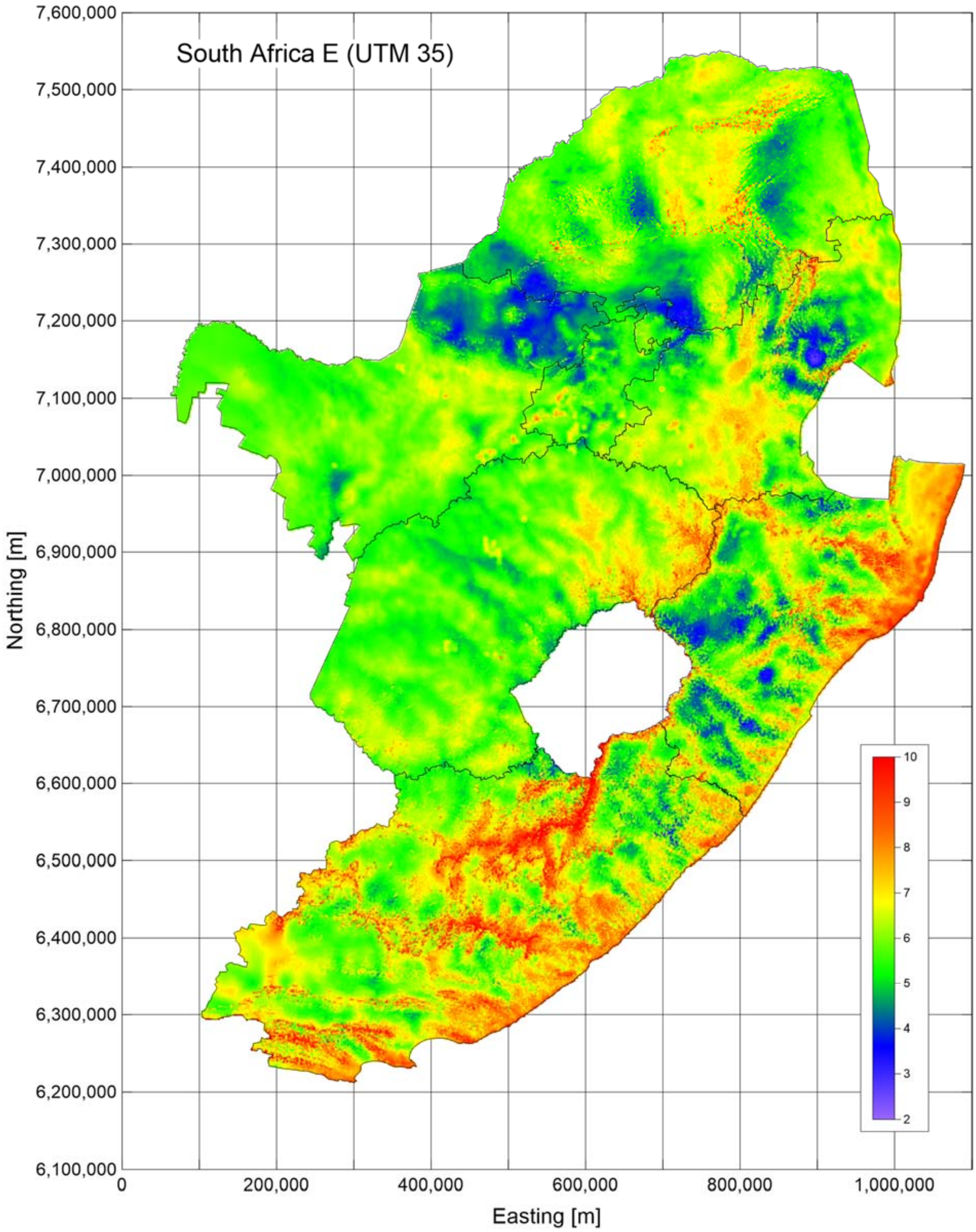
South Africa mean power density [Wm^{-2}] @ 100 m a.g.l.



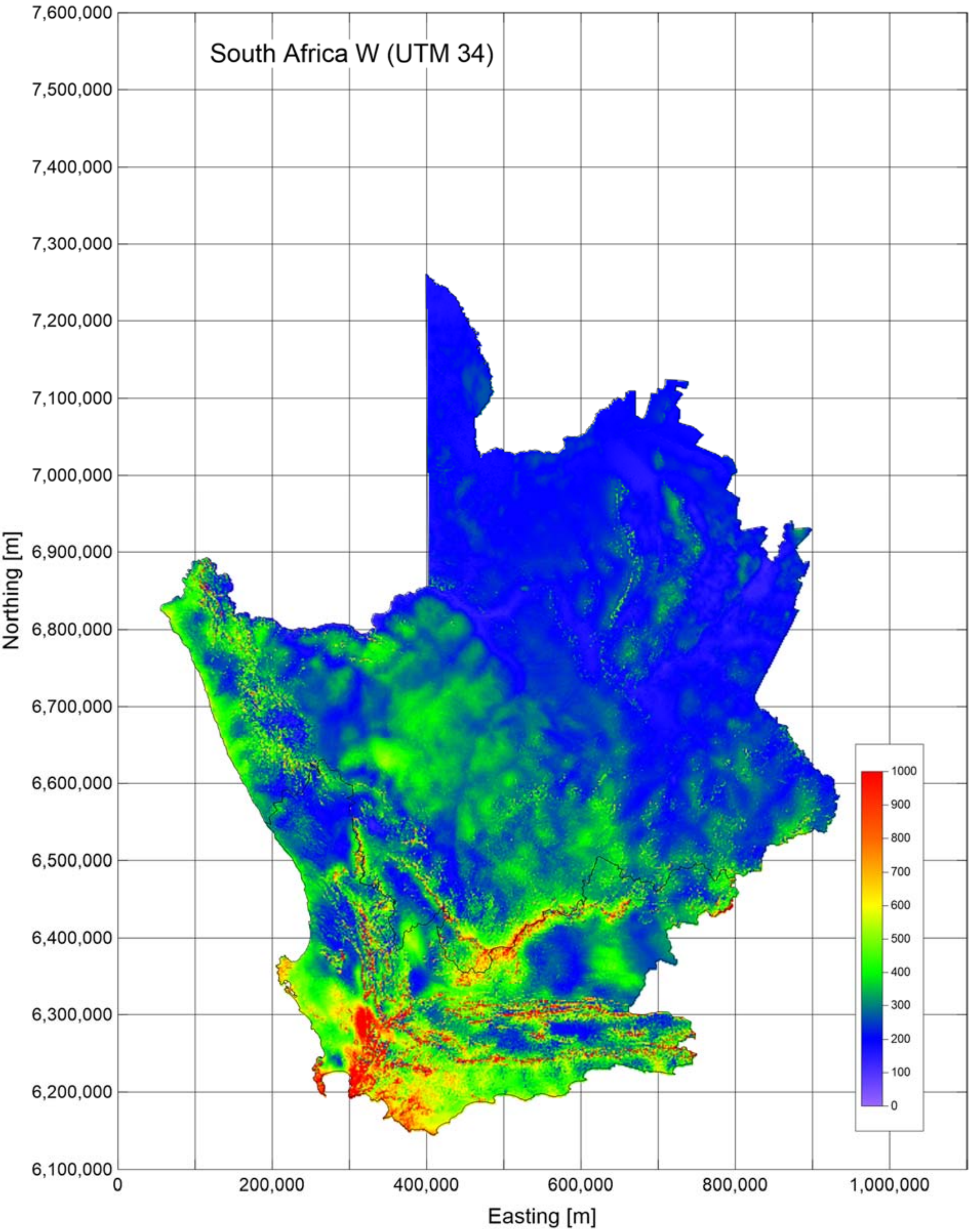
South Africa W mean wind speed at 100 m a.g.l.



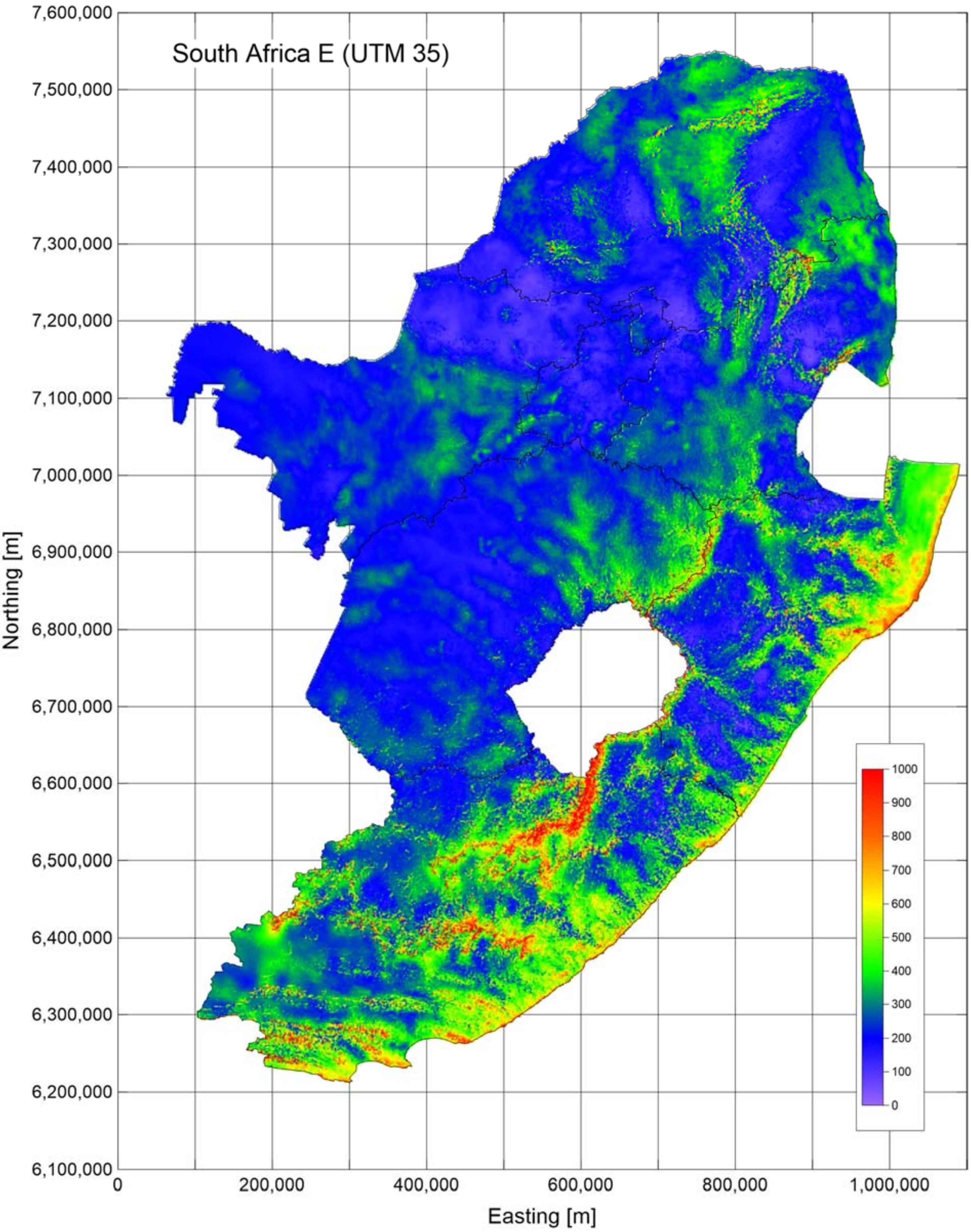
South Africa E mean wind speed at 100 m a.g.l.



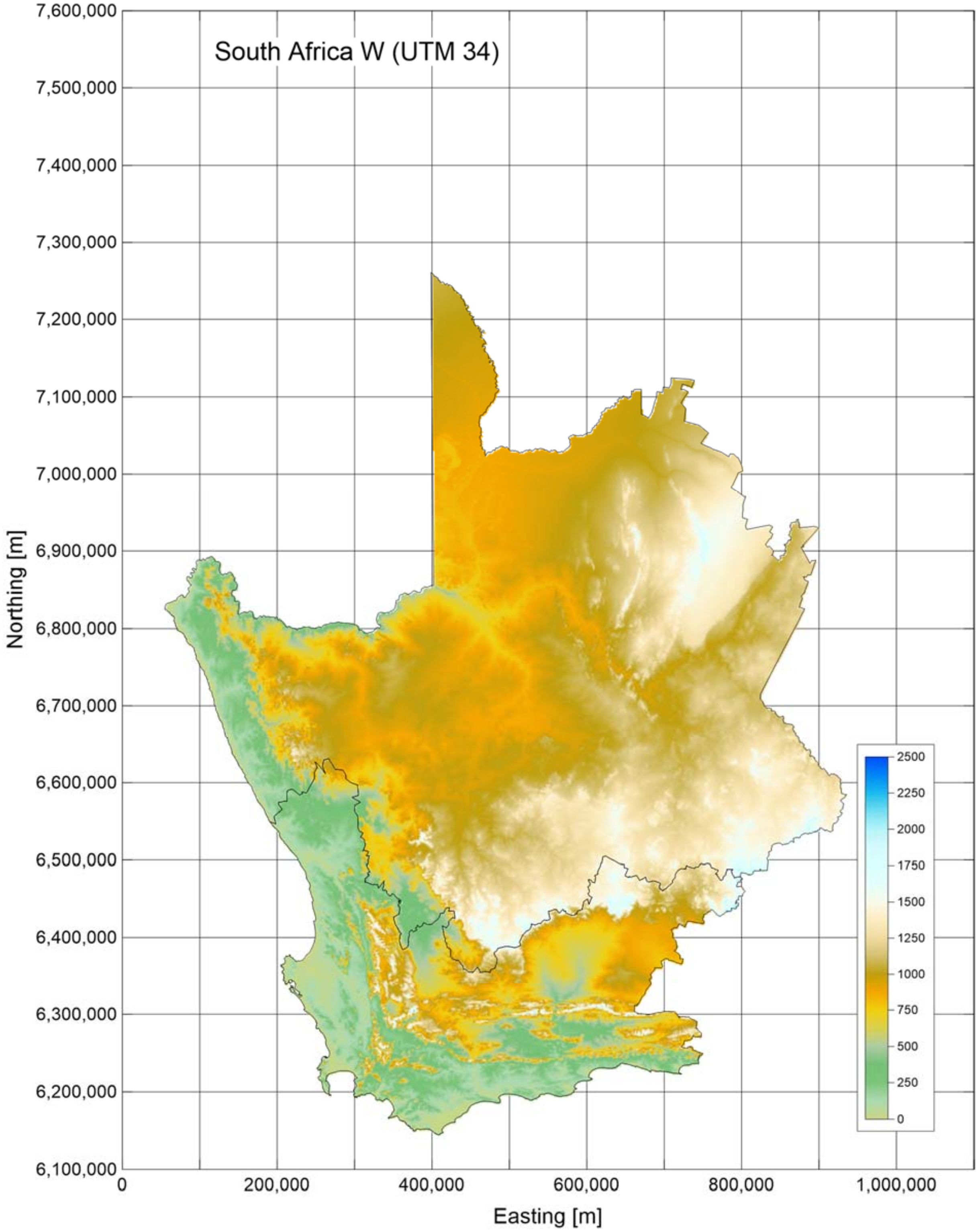
South Africa W mean power density at 100 m a.g.l.



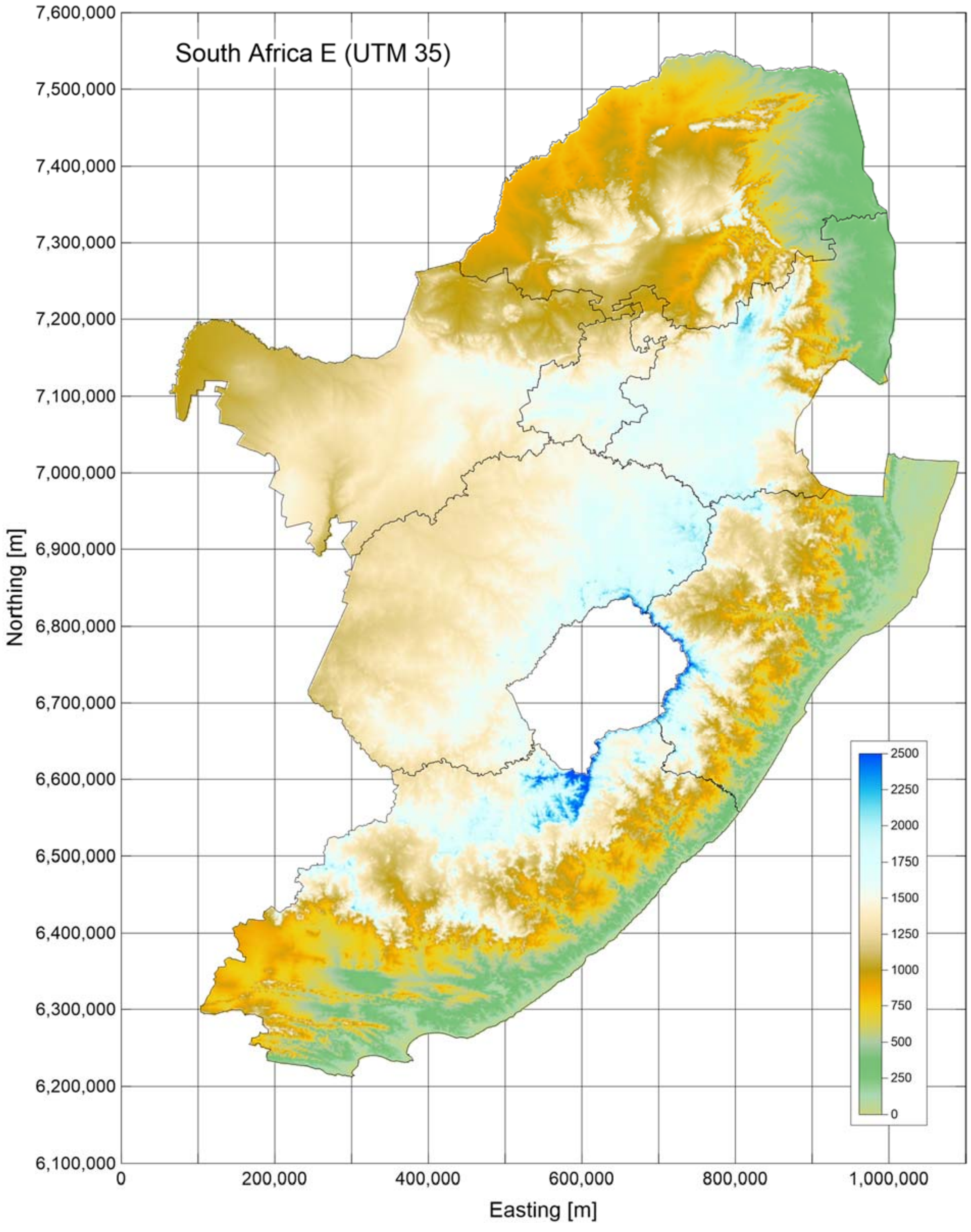
South Africa E mean power density at 100 m a.g.l.



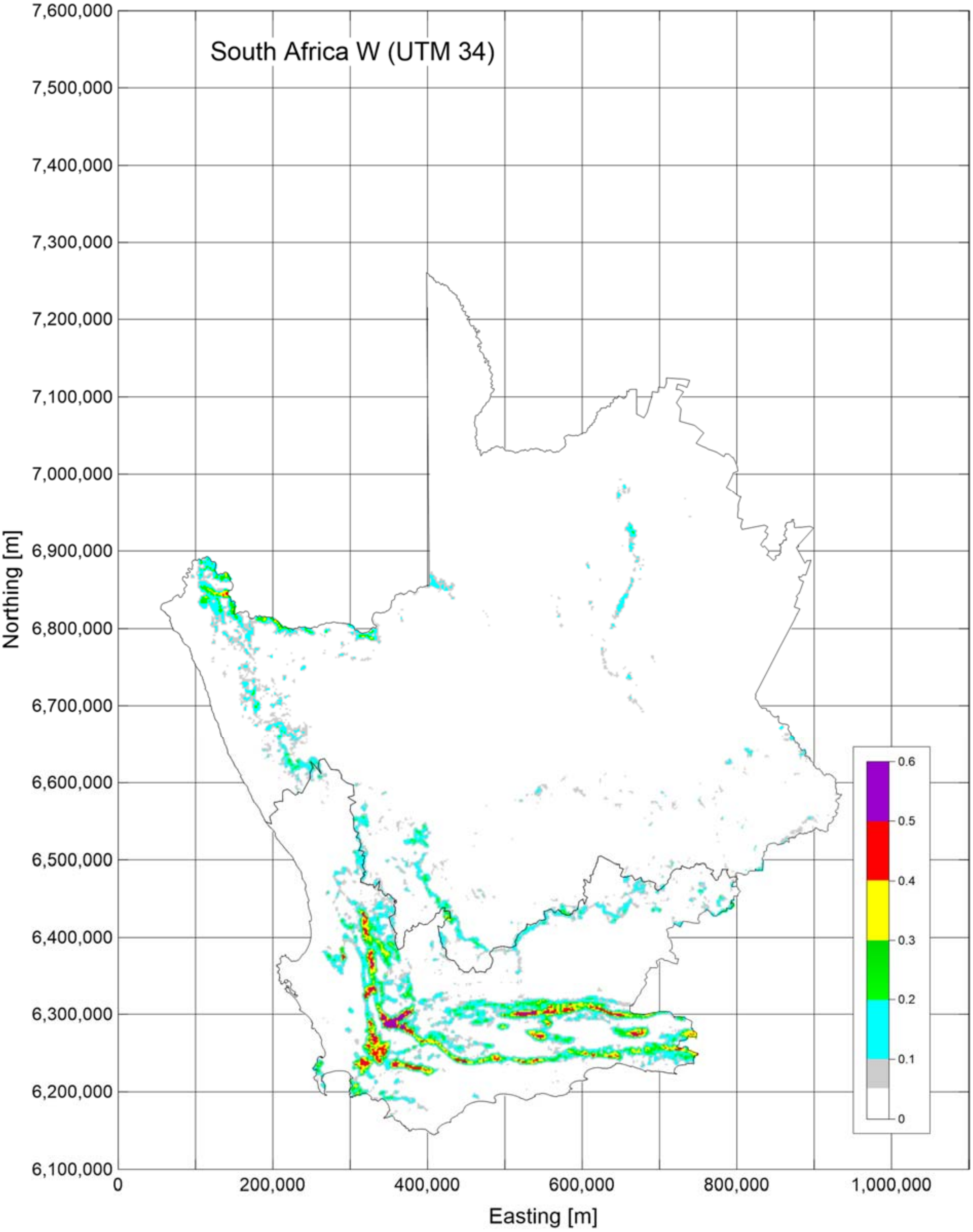
South Africa W elevation



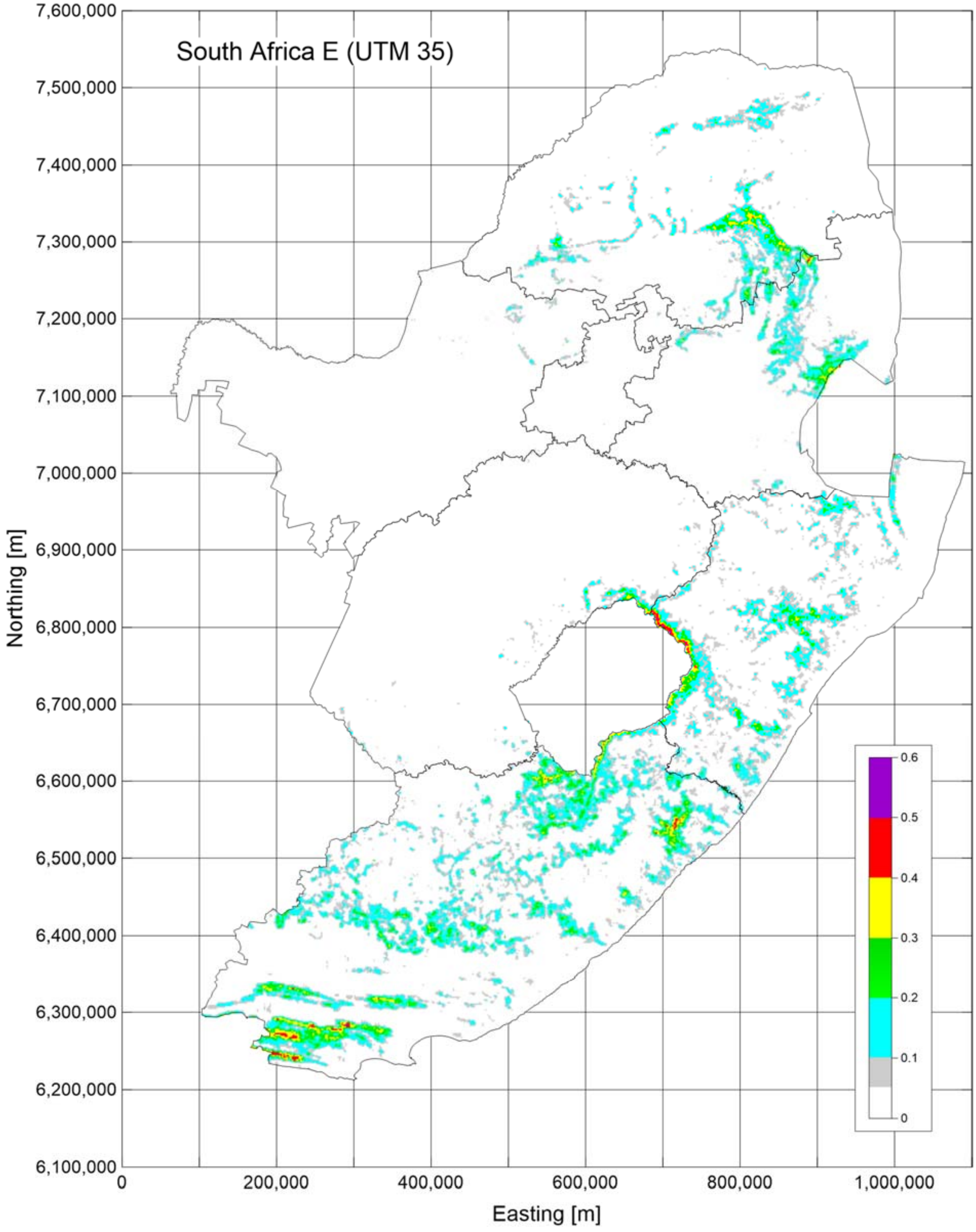
South Africa E elevation



South Africa W ruggedness index



South Africa E ruggedness index



D Files on files.dtu.dk

Files available on files.dtu.dk or the WASA project download site are listed below; the format of files given in the metadata documents:

- Database of SEA 1 characteristics
- Database of SEA 2 characteristics
- Database of wind atlas files

Database of SEA 1 characteristics

One ZIP archive per province; plus one for Limpopo @ 15 km NWA resolution:

1. ZA_EC_250_EMPR_20171023.zip
2. ZA_FS_250_EMPR_20171024.zip
3. ZA_GT_250_EMPR_20171024.zip
4. ZA_LP_250_EMPR_20171024.zip
5. ZA_LP_250(15km)_EMPR_20171031.zip
6. ZA_MP_250_EMPR_20171025.zip
7. ZA_NC_250_EMPR_20171024.zip
8. ZA_NL_250_EMPR_20171025.zip
9. ZA_NW_250_EMPR_20171025.zip
10. ZA_WC_250_EMPR_20171023.zip

Same type of files for WASA 1 domain, but without elevation and RIX files:

1. WASA1_ZA_EC_250_MP_20171103.zip
2. WASA1_ZA_NC_250_MP_20171103.zip
3. WASA1_ZA_WC_250_MP_20171102.zip

Metadata documents and graphics files for data sets:

1. High-Resolution Wind Resource Map for WASA 1 domain.pdf
2. Interim High-Resolution Wind Resource Map for South Africa.pdf
3. South Africa mean wind speed 100 m.kmz
4. South Africa mean power density 100 m.kmz

Database of SEA 2 characteristics

One ZIP archive per province:

1. EC Prod upd_ClimateSectorwise.zip
2. FS Prod upd_ClimateSectorwise.zip
3. GT Prod upd_ClimateSectorwise.zip
4. LP Prod upd 2_ClimateSectorwise.zip
5. MP Prod upd_ClimateSectorwise.zip
6. NC Prod upd_ClimateSectorwise.zip
7. NL Prod upd_ClimateSectorwise.zip
8. NW Prod upd_ClimateSectorwise.zip
9. WC Prod upd_ClimateSectorwise.zip

Same type of files for WASA 1 domain (given per province, but should be used *only* for the WASA 1 domain):

1. EC WASA1 Prod 1_ClimateSectorwise.zip
2. NC WASA1 Prod 1_ClimateSectorwise.zip
3. WC WASA1 Prod 1_ClimateSectorwise.zip

Database of wind atlas files

One ZIP archive per LIB file data set for all of South Africa:

- WASA1_Libs.zip (WASA 1 3-km data; 37,847 LIB files)
- WASA2_Libs.zip (WASA 2 5-km data: 44,326 LIB files)

Coordinates of LIB files in CSV or DAT files:

- WASA1_Libs_coords.csv
- WASA1_Libs_coords.dat
- WASA2_Libs_coords.csv
- WASA2_Libs_coords.dat